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Materials Recovery Facilities in the United States Virgin Islands: A Regional Facilities Location Model Study

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MATERIALS RECOVERY FACILITIES
IN THE U. S. VIRGIN ISLANDS:
A REGIONAL FACILITIES LOCATION MODEL STUDY

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ABSTRACT

MATERIAL RECOVERY FACILITIES IN THE U. S. VIRGIN ISLANDS: A REGIONAL FACILITIES LOCATION MODEL STUDY

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Old Dominion University, 1994
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Continental municipalities have derived many benefits from the economies of scale associated with a regional approach to facilities location and management planning. Centralized solid waste processing facilities is an example. Island communities, however, surrounded by miles of ocean, are constrained to a fragmented approach to the facilities location solution. This research was conducted to determine if the regional paradigm suggested in the literature is applicable to a set of island communities connected by an ocean transportation infrastructure. A linear programming (LP) model, constraints and data requirements were developed and applied to a network of islands. A series of hypothetical material recovery facilities (MRF) location scenarios were studied using actual and projected data obtained for the three-island territory of the U. S. Virgin Islands. In all cases, a significant reduction in capital construction expenditures was realized. For the selected data values in the research, transportation and operating costs increased as expected, but by a surprisingly small amount. This research concludes that the regional approach to economic and environmental facilities planning for island communities is valid. Future research involving larger systems of islands and stochastic processes is suggested.

To Carolyn and Catarina

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I would also like to acknowledge the Lord, who in His infinite wisdom, conferred upon me these talents, of which I am grateful.

I acknowledge the wonderful friends I have made and the experiences that we have shared on this journey called "Life."

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1. INTRODUCTION

Background

The islands of the Caribbean stretch from the coast of Florida, south-southeast to the continent of South America. Cuba, Hispañola (Haiti and the Dominican Republic) and Puerto Rico comprise the Greater Antilles. The U.S. and British Virgin Islands, through the island of Martinique, make up the Leeward Islands. The islands of All Saints and Barbados, westward to the island of Aruba are the southernmost group, the Windward Islands of the Lesser Antilles. Scattered among the major islands are hundreds of smaller islands, some inhabited, others not. These islands were once the rich prize of European nations for their spices, sugar and rum trade, and are again approaching the center of the global stage for tourism and industrial development. With the explosive growth of indigenous and transient population, the hotel and resort sector, light and medium manufacturing industries, and oil and gas refining, the ecological health of the Caribbean region is beginning to attract the attention of local and international organizations.

Considering that each island is separated by miles of ocean, urban development is conducted within a fragmented framework. Each island handles its own urban affairs and infrastructure development without consideration for possible interaction with neighboring islands. While this fragmentation may seem to be the only framework applicable to island communities, research shows that modern continental municipal infrastructure development evolved from a similarly fragmented planning approach [Tarr and Dupuy, ed. 1988]. Municipalities had developed their own infrastructure without much consideration for neighboring communities. As their boundaries expanded and available land resources diminished, cooperative development between municipalities became the norm. The development of central facilities that service a large number of municipalities is just one example of regional cooperation.

Individual island community per capita consumption, energy usage and waste generation patterns are similar in most respects to continental municipalities. Island community per capita growth patterns are also quite similar. While continental communities enjoy the benefits of regional cooperation, island communities continue to study municipal growth management alternatives within a fragmented framework. The economic growth envisioned for the entire Caribbean region focuses attention on urban development issues that must be addressed by individual island communities. A continued fragmented approach to the study of island community development may lead to a sub optimum decision inappropriate for regional economic growth.

The Waste Management Problem

Municipalities on the American and European mainland all face solid waste management problems. These municipalities share one very important characteristic: a well developed urban infrastructure. This local infrastructure can support a vast array of municipal solid waste management system alternatives. Siting solid waste processing facilities within an urban transportation infrastructure is an important decision in the study of any alternative system. The minimization of transportation costs between sources of municipal solid waste and processing facilities and disposal sites is frequently the critical factor in the facility location decisions. Given an optimum design, facility location minimizes the cost of the entire system, while maximizing the utility to the community it serves. A highly developed and varied regional transportation infrastructure increases the number of alternatives that must be analyzed. For continental municipalities, access to major highways, railroads and canals, and a relatively large landmass creates a nearly infinite set of possible sites for planned facilities.

In contrast, island community transportation networks are comparatively rudimentary and interaction with neighboring island communities and the problems of distant disposal sites are not factors in facility location decisions. Furthermore, land area available to island communities is severely constrained by island size and available sites compete at a premium with tourism and housing development. This simplified logistics network structure makes the transportation problem relatively insignificant in the facilities location decision. However, the limited number of available on-island sites for solid waste management facilities reduces the number feasible options immensely.

Until about 20 years ago, the problem of collecting and disposing municipal solid waste fell mostly on the shoulders of local communities [Gottinger 1991]. As the quantity of municipal solid waste grew and the number of available local sites for disposal diminished, a centrally located municipal solid waste facility afforded mainland communities the advantage of economy of scale. These facilities service multiple municipalities over a relatively large geographic region, greatly reducing the cost per unit of solid waste processed. To contrast once again, island communities do not generate sufficient quantities of solid waste material to make large-scale processing facilities feasible. Yet, at the same time, the islands are too small to adequately absorb the solid waste stream that is generated by its population and industries.

The number of solid waste management options available for every phase of local operations is rather substantial. The waste collection options include mixed waste, source-separated waste, and intermediate collection centers or combinations of the three. The solid waste stream collected can then be composted, incinerated, utilized as refuse-derived fuel for waste-to-energy conversion, processed for resource recovery or any combination of these options. Resources that can be recovered include paper, old corrugated cardboard, various types of plastics, aluminum and ferrous metals, and some textiles. Material not recovered (residue) is processed as refuse-derived fuel, as raw material for composting or buried directly at a landfill. The solid waste management option selected for a local community may be appropriate for that community from a fragmented system point of view. From a regional viewpoint, however, as in the regional solid waste management scenarios discussed above, a regional solid waste management option may prove to be the best solution for an entire region.

Problem Statement

Caribbean island communities currently handle urban growth planning studies from a fragmented point of view. Solid waste management alternatives are limited to small-scale systems deemed appropriate for each individual island. Regional planning, on the other hand, may make a measurable impact on the number of economically feasible solid waste management options available to the region. An optimum regional solid waste management system configuration may be best when compared to a fragmented system of local island options.

The U. S. Virgin Islands is a territory of the United States in the Caribbean and is comprised of three main islands: St. Croix, St. Thomas and St. John. The government, economy and per capita growth patterns are similar across all three islands. Solid waste management is currently handled by each island community in isolation from the other two islands. It is proposed in this research that the current fragmented approach is deficient in that lower-cost solid waste management system alternatives may be available to the region as a whole. A territorial viewpoint for planning may make a measurable impact on the number of feasible alternatives available to this small region.

Research Objective

The objective of this research is to investigate the problem of analysis of solid waste management options for the territory of the U. S. Virgin Islands from a regional perspective. A centrally located mixed-waste material recovery facility (MRF) is the alternative for study. The linear programming model for the quantitative analysis of MRF siting on a territorial basis is proposed to determine:

1. The number and location of MRF's required to process the solid waste stream from the entire territorial U.S. Virgin Islands.
2. The recovered resource should be processed by each facility and shipped to post-consumer markets.
3. The set of islands to be served by each material recovery facility.

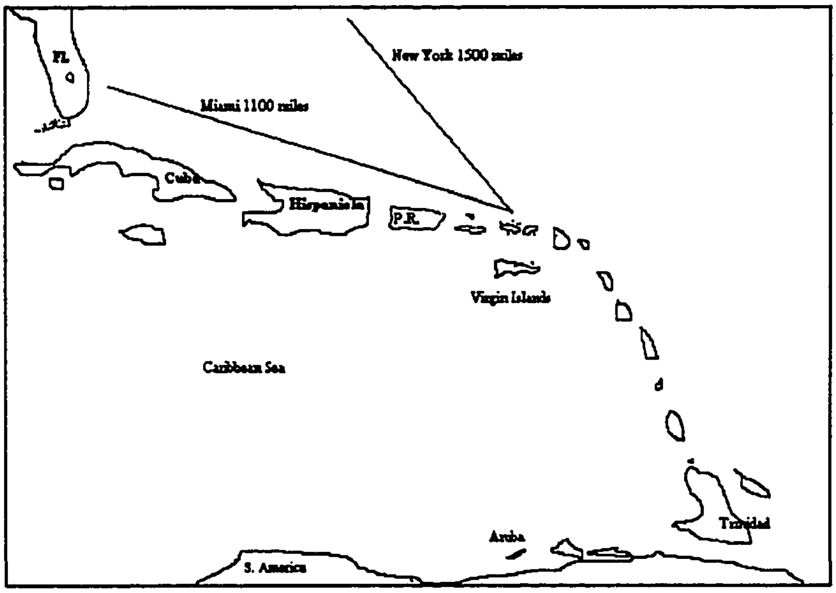

Figure 1. The Caribbean Region and Virgin Islands

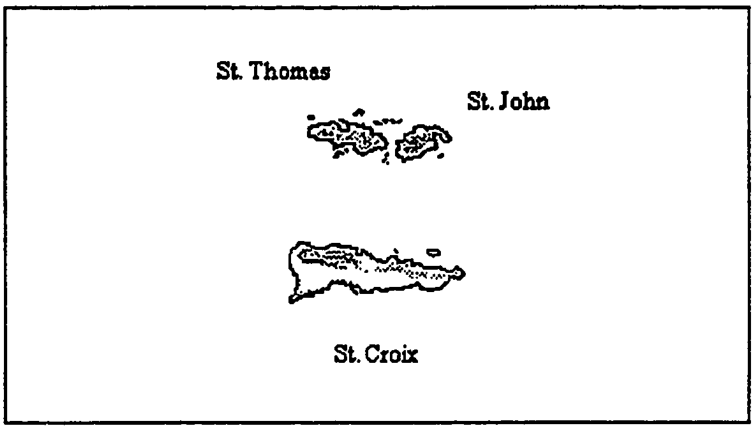

Figure 2. The U. S. Virgin Islands

2. LITERATURE REVIEW

Facility location

Facility location modeling is not new to operations research. The determination of sites for depots and warehouses has been of strategic importance in the planning and operation of any product distribution system. Solutions range from intuitive and subjective approaches to extremely sophisticated analytic methods. Aikens summarizes some of the significant contributions that have been made and the current state of knowledge in mathematical programming. Models have been developed for simple, single commodity, linear deterministic systems, increasing in complexity to the multi-commodity, non-linear stochastic systems [Aikens 1985].

Other authors, too, discuss specific areas of facility location. Ballou develops facilities location from a business logistics framework. This includes the entire logistics network planning process, single and multiple facility location, and transportation and storage processing decisions [Ballou 1992]. Love, Morris and Wesolowsky address the facilities location problem from a mathematical model and methods point of view. Specific models are developed for site generation and selection, and location/allocation [Love et al. 1988].

Brown and Gibson developed a quantified factor model for comparison of selection factors in a multi-facility location decision, the results of which can then be used as the basis for further analysis. Their research helped fill the void that existed between early location theory, which ranged from lists of subjective factors used as guidelines, and the mathematical models that utilized only monetary factors. An objective function was developed based upon weighed location factors, such as the availability of adequate power, labor and wage rates and community attitude and services. It was shown that any factor could be accommodated by this model [Brown and Gibson 1972].

AT&T applied mixed-integer, linear programming (MILP) to assist customers in siting telemarketing facilities based upon location-driven factors, such as labor, facility and telecommunications costs and market-driven factors, such as call volume by region and time zones. A fully implemented system with graphics and interactive capabilities was developed on high-end personal computers by their Business Operations Analysis division [Spencer 1990].

Hansen applies facilities location models to urban planning. An example is locating public facilities for the maximum benefit of a community. It was shown that by reinterpreting the methods, one can also maximize the distance of a facility from centers of population, such as landfills and other odorous processing facilities, while minimizing transportation costs [Hansen 1987].

Solid Waste Management

Development of a solid waste management system within a municipality is a significant undertaking. Geoffrion notes that "facility location analysis is just the beginning (if you do it right)!" It requires significant research and planning. A defined system mission, a comprehensive analysis of system design alternatives including non-recovery disposal options, energy and resource recovery options and hazardous waste environmental issues are a few of the problems that must be addressed [Geoffrion 1980]. Lipták addresses the management issues and technology alternatives facing the municipal decision maker and is a good place to begin research for a local project. Municipal solid waste composition and quantities generated, sewage sludge and hazardous waste disposal and the health effects of incineration are covered thoroughly in her work [Lipták 1991]. Conn discusses representative solid waste management planning considerations at the state level. A booklet was developed specifically for the Commonwealth of Virginia (USA), but is readily adaptable to any region [Conn 1990]. The United States Environmental Protection Agency (EPA) in particular, has published a very detailed project management model for the evaluation of resource recovery alternatives. Collection schemes, proposed site analysis, material recovery facility (MRF) design, waste stream and market analysis, development of a transportation model, operational utilization of the MRF and municipalities to be serviced, are just a small fraction of the required tasks described in excellent detail in this work [EPA 1979b]. Additional literature on waste stream analysis methods, economic analysis of municipal systems and specific resource recovery technology alternatives is readily available in the literature [EPA 1979a; EPA 1981; Gottinger 1991; Swartzbaugh et al. 1993; Rogoff and Williams 1994].

A group of authors, Lund, Tchobanoglous, Anex and Lawver, just recently applied linear programming (LP) techniques to the analysis of material recovery facility design and operations. Given a set of design parameters for a candidate MRF, their proposed LP model selects the least-cost design and determines the optimum number of sorting stages to employ based upon the expected demand for recovered products. The model allows for updating material recovery factors to adjust for changing product demand throughout the operating phase of the MRF [Lund et al. 1994].

Facilities Location and Solid Waste Management

While product-to-customer systems are generally designed around distribution factors, solid waste management problems are collection-based. LP techniques were applied to municipal sanitation vehicle routing and scheduling to minimize total travel distance and operating time subject to vehicle capacity. The system was implemented in the town of Oyster Bay, New York (USA) [Bodin et al. 1989]. A study by the Center for Plastics Recycling Research at Rutgers University applied MILP to the MRF location problem at both the regional and metropolitan level. Two case studies are discussed in this work. The first was a study of siting regional MRFs for the state of New Jersey using aggregated municipal solid waste streams. The second was the location of MRFs within a single municipality, the metropolitan area of Atlanta, GA. This research verified that fewer, but larger facilities are preferred, and that they be located closest to centers of highest solid waste generation [Center for Plastics Recycling Research (CPRR), Rutgers University, New Jersey Tech Report #71 1992].

Transportation Infrastructure Considerations

Technology advances has driven the development of the urban infrastructure. Studies of its effects on inter- and intra-city networks include not only communication, water and energy distribution, but also solid waste transportation and disposal. As cities grow larger, the fragmentation of individual transportation networks tends to diminish as regional cooperation forces a more integrated approach toward urban planning and development [Tarr and Dupuy, ed. 1988].

The historically fragmented approach to solid waste management has severe consequences, as illustrated in Rose's article: Germany's product packaging recycling program, launched under Environment Minister Klaus Topfers packaging ordinance in 1991, coupled with an unanticipated level of consumer enthusiasm, caused a glut of material that the existing collection and processing system could not handle. Faced with bankruptcies, financial support was extended to the waste collectors and processors. The result of these subsidies was material relatively cheap when compared to other country's products. Neighboring European Community (EC) governments called for Germany to halt exports or to at least scale back their program - the inexpensive recovered materials made these countries' recycling efforts uneconomical [Rose 1993]!

The trend toward regional infrastructure development is not limited to large landmasses. The Mediterranean Environmental Technical Assistance Program (METAP), funded in 1993 by the European Investment Bank and the World Bank, found that municipal solid waste management in nine cities around the Mediterranean Sea suffered from ill-designed and managed open dumps and no resource recovery or recycling facilities. The report concluded that because of the high costs of [MRF or recycling] facility construction and solid waste transportation costs, informal resource recovery (i.e. "self-employed waste collectors") should be encouraged. Additional research was being funded to determine the feasibility of developing regional cooperation in solid waste management across national and ocean boundaries [Rose 1993].

The type of oceanic-region solid waste management problem above is not unique to any specific part of the globe. A study conducted in the Oceania Islands of the South Pacific (Micronesia, American Samoa, etc.) determined that the area's sustained economic growth and environmental health was intimately coupled to regional solid waste management. The authors citing the research noted that transportation between islands located tens of thousands of miles apart is a significant factor in the development of alternatives for this region [Crawford 1993].

The island communities of the Caribbean, too, are well aware of similar problems facing their economic growth and environmental stability. In the keynote address to the Caribbean Energy Conference and Technology Exposition, held 23-25 October, 1993 in St. Thomas, Virgin Islands, Young-Hinds argued that "the carrying capacity of our decidedly limited land masses... [is] ...far more critical for island micro states" than for continental communities. She concludes that regional cooperation on waste management initiatives, such as establishing Caribbean-based recycling centers, may enjoy the economies of scale afforded similar regional facilities [Young-Hinds 1993].

Several major problems limit the number of solid waste management alternatives available for individual islands and is summarized below from various sources:

a) There are too few locations available for solid waste disposal facilities.

b) The quantity of solid waste material generated by individual islands is not sufficient to be economical for medium or large scale material processing facilities.

c) Current waste collection practices (non-staffed, roll-on/roll-off bins centrally located) is not compatible with source-separated recycling alternatives.

d) Local markets for the products derived from the solid waste stream is nearly non-existent; all existing markets are distant.

[MITRE Corporation 1979; GBB "Report on Markets" 1994; Dominique 1994; Beagles 1994; Vauthrin 1994; Willock 1994].

Results of Literature Review

The area of facility location planning models is well researched. Similarly, the application of mathematical programming to planning models for regional waste management and the MRF design optimization problems are well developed. Economic, political, site-specific and technological factors have all been addressed. Although the regional aspect of facility location and specifically its application to the solid waste management problem for ocean and island communities is apparent, the solution represents a major shift in paradigm and there is a void in the body of research.

This research is conducted to investigate the application of existing strategic facilities location models to a given set of island communities. Local vehicle routing and collection methods, the resource recovery technology alternatives selected for study (waste-to-energy, shredding, landfill, and source-separated or mixed-waste MRF), the political and other locality-specific decisions are beyond the scope of this research. These factors can, however, be incorporated into the model proposed.

The works of the CPRR and Lund provides the basis for this study. Their application of facility location and MRF design models are flexible enough to provide the tools required to assist decision makers in the analysis of the transportation and location options available to regional island communities [CPRR Tech Report #71 1992; Lund 1994]. Systems of islands, such as Oceania, island states and countries in and around the Mediterranean Sea, and, of course, the Caribbean Sea, should benefit from this study.

3. RESEARCH METHODOLOGY

Introduction

Classical facility location models are generally non-linear due to the Euclidean distance calculations required to determine candidate facility sites on a continuous plane defined by a large landmass [Love et al. 1988]. In considering island communities, however, the number of possible facility locations is reduced to a discrete set of either one or more locations per island or from among several candidate islands or some combination of both. Transportation costs are essentially a linear function of the applicable shipping rate structure and the quantity of material moved.

In this research, the mixed-integer, linear programming (MILP) model is used for analysis of the MRF location decision. The standard linear programming model focuses only on variable costs of MRF operation. The proposed model is allowed to select from a set of candidate MRFs, each with its associated fixed capital construction costs. The selection variables are integer 0/1 and the model is mixed-integer.

The Facility Location Problem

The set of possible sites for a facility can be either continuous or discrete. A continuous set of sites arises when the possible locations is described as points on a plane. Examples include determining a facility site within a county, a state, a country or a region. Methods exist to generate a set of possible sites based upon center-of-gravity of population densities or maximum travel distance. Once a discrete set of possible locations is generated, the problem reduces to a discrete-location problem. At this point, actual location attributes can be prioritized and an optimum location selected [Love et al. 1988].

For the relatively simple case of a single-facility location, the objective may be to minimize new construction costs, or maximize the community service area. The multi-facility location problem involves locating two or more facilities simultaneously. This problem is more difficult, since these facilities usually interact with each other and with existing facilities. Further, the interdependencies between these multiple facilities can be described as following stochastic, non-linear or linear functions. When locating facilities within an existing system, management wants to know the minimum cost of rearranging the transportation network, how to maximize customer service within the new structure or whether it is economical to design a completely new system.

Another aspect of locating multiple facilities involves the analysis of product flows between existing facilities and the new facilities. This is referred to as the location-allocation problem [Love et al. 1988]. The location of repair depots and warehouses fall into this class of problems. In addition to locating the facilities, customer demand must be assigned to a particular facility. Flows through the distribution network can be either capacitated or uncapacitated, depending on whether nodes, the depots and warehouses or arcs, the transportation mode, have practical maximum holding or carrying capacities.

The concept of echelon or stages between the supply and demand sites increases the complexity of the problem. The simplest model is the single-stage system: products are routed from a facility direct to a customer. In a two- or more-stage system, also referred to as a transshipment system, products can be routed via an intermediate facility, usually a dealer warehouse or tank farm. Note that if a facility is co-located at either the source or the demand site, the connecting network may be reduced to a single-stage system [Love et al. 1988]. If it is located at an intermediate distance from the supply or demand site in such a way as to minimize distribution costs, then it is a multi-echelon system. The objective of the model remains to minimize selected system parameters, determination of service area and the allocation of product demands to specific product sources.

Model Development

The research problem of locating new facilities within a set of islands, considering the flow of products through the proposed transportation network and determination of the service area, falls within the class of multi-facility, location-allocation models [Love et al. 1988]. The process of locating any facility involves an analysis of the transportation network that connects the supply location to the demand location for a quantity of product, which must be shipped via a particular route or mode, to a demand location (Figure 3). If the supply and demand locations are known, the transportation problem to be solved is illustrated as:

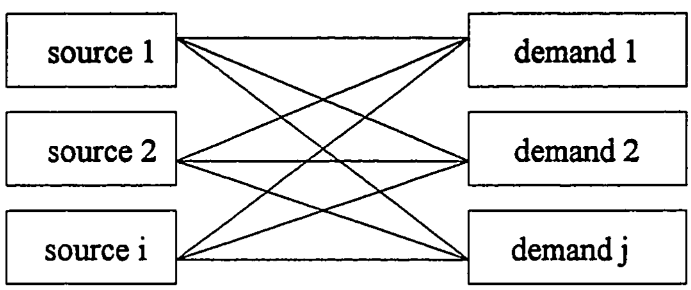

Figure 3. Single-Echelon Transportation Network

The objective is to design the network such that transportation costs are minimized and all demands for products met without outstripping the available supply. The linear programming (LP) representation of this single-echelon, single-commodity, uncapacitated network is:

minimize $\Sigma\, c_{ij}\, x_{ij}$

subject to

$$\Sigma\, x_{ij} = S_i, \quad \text{for all } i$$

$$\Sigma\, x_{ij} = D_j, \quad \text{for all } j$$

where:

c_{ij} = transportation cost from source i to destination j,

x_{ij} = product flow from source i to destination j,

S_i = the total supply at source i, and

D_j = the total demand at destination j.

If demand sites are known and the objective is a minimum cost network based upon the selection of one or more supply facilities from a set of candidate sites, then the formulation expands to the single-echelon, location-allocation model [Love et al. 1988]:

minimize $\Sigma\, c_{ij}\, x_{ij} + \Sigma\,(f_i + v_i)\, x_{ij}\, z_i$

subject to:

$$\Sigma\, x_{ij} = S_i, \text{ for all } i$$

$$\Sigma\, xij = D_j, \text{ for all } j$$

$$z_i \in \{0,1\}$$

$$x_{ij} \geq 0 \text{ for all } i, j$$

where

f_i = setup cost at facility i,

v_i = operating cost at facility i, and

z_i = {1, if facility i is selected, and 0 if facility i is not selected}

Establishing an intermediate facility introduces a second echelon into the distribution network as shown in Figure 4.

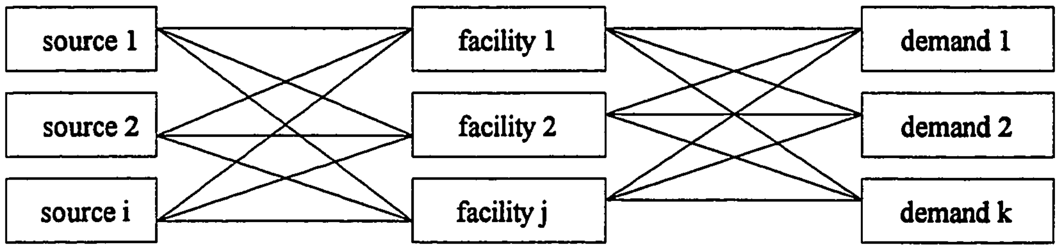

Figure 4. Two-echelon, transshipment network

If the source and demand locations are known and the objective is to establish facilities at the intermediate nodes of the network, then the mathematical representation of this problem is:

minimize $\quad \Sigma\, b_{ij}\, x_{ij} + \Sigma\, c_{jk}\, y_{jk} + \Sigma\, (f_j + v_j)\, x_{ij}\, z_j$

subject to:

$$\Sigma\, x_{ij} = S_i, \quad \text{for all } i$$

$$\Sigma\, y_{jk} = D_k, \quad \text{for all } k$$

$$\Sigma\, x_{ij} = \Sigma\, y_{jk}$$

$$z_j \in \{0,1\}$$

$$x_{ij} \geq 0$$

$$y_{jk} \geq 0$$

where

b_{ij} = transportation cost from source i to facility j,

x_{ij} = product flow from source i to facility j,

c_{jk} = transportation cost from facility j to demand k,

y_{jk} = product flow from facility j to demand k,

f_j = setup cost for facility j,

v_j = operating cost for facility j, and

z_j = {1 if facility j is sited, and 0 if facility j is not sited}

Facility Analysis in Regional Waste Management

The solid waste collection options include mixed waste, source-separated waste, and intermediate collection centers or combinations of the three. The solid waste stream collected is either composted, incinerated, utilized as refuse-derived fuel (RDF) for waste-to-energy conversion, processed at an MRF for resource recovery or any combination of these options. Resources that can be recovered include paper, old corrugated cardboard (OOC), various types of plastics, aluminum and ferrous metals, and some textiles. Material not recovered (residue) is processed either as RDF, as raw material for composting or buried directly at a landfill [Swartzbaugh et al. 1993]. This research addresses the location of an MRF within the scope of regional solid waste management.

As the entire MSW stream is processed through a typical MRF, a variety of products can be recovered. The products considered in this research are grouped as follows:

a) paper:	newspaper, magazines and junk mail,
b) OCC:	old corrugated cardboard and packaging,
c) plastics:	PET (polyethylene terephthalate)
	HDPE (high-density polyethylene)
	PVC (polyvinyl chloride), and
	LDPE (low-density polyethylene)
d) glass:	clear, green, crushed,
e) metals:	ferrous, aluminum, other non-ferrous,
f) organics:	textiles (rags, clothing and linen), and
g) CD:	construction debris (concrete, asphalt, and wood)

Material recovered as raw input to a composting facility are:

a) contaminated paper, OCC, and

b) food and yard wastes.

All other material is buried in the landfill. The quantity of material recovered is a function of the sorting technology employed at the MRF. A numerical recovery "rate" or "factor" is associated with each product for the specific sort technology utilized [CPRR Tech Report #71 1992; Swartzbaugh et al. 1993; Lund 1994]. If the MSW stream is source-separated, the recovery factor for those products can increase. Mixed waste processing contaminates paper products with other organic matter, food material and moisture. However, this material is ideal for composting [Rognoff and Williams 1994; Swartzbaugh et al. 1993; GBB "Reports on Markets" 1994].

Composting is selected as the primary use of recovered organics from the waste stream for the following reasons:

a) it is compatible with mixed waste processing. Local food preparation practices, a large proportion of tourism-related waste and a higher percentage of contaminated paper products makes for a rich resource for composting,

b) it can be implemented using relatively low technology,

c) operational history of composting is well established outside of the United States, in Europe and in under-developed countries, and

d) the compost product can be used for landfill cover, land reconditioning and reclamation, and is ideal for islands with a shallow topsoil layer, such as the Virgin Islands.

The MRF model, is illustrated below in Figure 5.

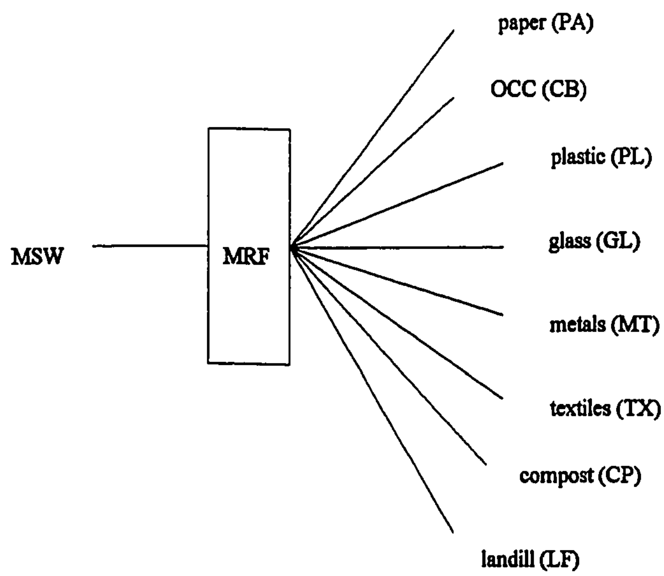

Figure 5. The Sorting Process of MSW at the MRF

The total amount of post-consumer product that can be recovered from a solid waste stream depends upon the proportion of that product in the solid waste stream. Prior to determining the economic feasibility of any recycling effort, an analysis of the solid waste stream is required. The literature discusses various statistical sampling methods, also referred to as a sort or a waste characterization report, for discovering the percentage of the various resources in the waste stream [Rogoff and Williams 1994; Swartzbaugh et al. 1993]. Given a waste stream of known characteristics, and applying the mixed-integer formulation of the facility location model discussed earlier, the total amount of recovered product that can be recovered in the MRF is represented as the following constraint:

$$\Sigma\, y_{jk} = \Sigma x_{ij} \times R_{jk} \qquad \text{for all MRFs at } j$$

where:

y_{jk} = the amount of product k recovered at MRF j,

x_{ij} = solid waste flowing from island i to MRF j,

R_{jk} = recovery factor at MRF j for product k, and

$\Sigma R_{jk} = 1$ at MRF j for all products k considered.

R_{jk} is pre computed by:

$$R_{jk} = u_{ik} \times v_{ij}$$

where:

u_{ik} = is the percentage of product k in the solid waste stream from island i, and

v_{jk} = is the percentage of product k that can be recovered from solid the waste stream by MRF j.

Assumptions

In order to establish a consistent basis for analysis in the research, certain assumptions have been made in regard to how solid waste and recovered product streams and costs and revenue would be handled. The following assumptions were made for this study:

1. The mixed-waste material recovery facility (MRF) is the only solid waste management alternative considered in this study.

2. Currently, there is not any central MRF located in the U. S. Virgin Islands. All facilities will be new construction.

3. The quantity of solid waste generated for each island is determined or projected. Currently, all waste is disposed of at landfill facilities. If an MRF was opened, the site

would become the destination for the island's and, if feasible, the territory's mixed waste stream. The landfills will continue to absorb the residue, but in a reduced quantity, prolonging their useful life.

4. Transportation costs from sources of waste to the MRF, and from the MRF to markets, are source-to-destination costs. Actual distances between sources and destinations are incorporated into the rate structure and will not be specifically addressed.

5. For this study, all sources of solid waste can be considered to come from a single aggregate stream. Solid waste collected on each island is hauled a relatively short distance, less than 15 miles, to any landfill or MRF. Transportation costs are based upon local rates.

6. Material losses through any facility or in transit due to evaporation and degradation is handled by the recovery factor associated with each type of material that can be recovered from the solid waste stream.

7. Markets for recovered material are sufficiently distant from the region in this study. The destination of recovered products are assumed to be an aggregate of all markets outside of the study region, except where landfills and compost facilities are specified for each island.

8. The units used in the model are: ton(s), tons per day, dollar(s) and dollars per ton. The time period is one year.

9. Local sanitation vehicle routing and scheduling and MRF operation optimization is outside the scope of this study.

10. Political sensitivity, economic payback periods, operating and maintenance costs over the life of a facility, the risks associated with operating a single instead of multiple facilities, weather impact on shipping and other factors not otherwise specifically addressed, were neglected in this facility location study.

The proposed model network diagram is illustrated in Figure 6. Test scenarios developed in the next chapter will either constrain the model to site one MRF per island or the one MRF per island constraint will be relaxed to allow the model to select the optimum system configuration. Further, these scenarios are tested against the projected increase in the municipal solid waste (MSW) stream.

The Objective Function

The objective of this research is to minimize the total cost of the solid waste management system of the territory from a regional viewpoint. The constraints that follow impose restrictions on solid waste quantities, facility capacity and recovered product demands. The restrictions on the number and location of selected facilities considered in the model discussed in the following sections can be relaxed to allow selection of the optimum location and number of facilities to minimize facility construction, operating and all transportation costs. The objective function of the MRF location model is described as follows:

$$\text{minimize} \qquad \Sigma\, b_{ij}\, x_{ij} + \Sigma\,(c_{jk} - r_{jk})\, y_{jk} + \Sigma\, f_j\, z_j + \Sigma\, v_j\, x_{ij}$$

where

b_{ij} = transportation cost from source i to facility j,

x_{ij} = solid waste flow from source i to facility j,

c_{jk} = transportation cost from facility j to demand k,

r_{jk} = revenue from sale of recovered product from facility j at demand k,

y_{jk} = product flow from facility j to demand k,

f_j = setup cost for facility j,

v_j = operating cost for facility j

z_j = {1 if facility j is sited, and 0 if facility j is not sited}

Model Constraints

Various methods exist to model the capacity limitations of a network. Upper and lower bounds on both the transportation network (arcs) and the capacity of facilities (nodes) can be considered. In this research model, uncapacitated transportation along the arcs are considered. MRF's of various capacities will be examined. The feasible solution to the objective function above is subject to the following constraints:

a) the total municipal solid waste stream, x_{ij}, flowing from island i into MRF j is not more than the total solid waste supply, S_i, available from island i

$$\Sigma x_{ij} = S_i \text{ , for all i}$$

b) the total amount of product available for each considered, y_{jk}, is not more than the total that can be recovered from the solid waste stream, x_{ij}, entering the MRF:

$$\Sigma R_{jk} x_{ij} = \Sigma y_{jk} \quad \text{for all products k}$$

where

R_{jk} = the recovery factor at MRF j for product k

c) the total demand for the products considered, D_k, is less than or equal to the total available from all MRF's selected:

$$\Sigma y_{jk} \leq D_k \text{, for all products k}$$

d) the capacity of any MRF selected, Q_j, can not be exceeded by the solid waste flow, x_{ij}, through it:

$$\Sigma x_{ij} = Q_j z_j, \text{ for all sources i flowing to MRF at j}$$

where

Q_j = the MRF capacities considered in this model, and

z_j = the integer 0/1 selection variable for MRF at j

Note that the model can be constrained to the required number of facilities that must be selected or the restriction can be relaxed in order that the optimum network structure can be determined.

The model requires the following data:

a) MSW source and quantity generation per time period,

b) Capacity of MRF's considered,

c) MRF operating costs per unit of material processed during the time period, and

d) Transportation costs along all arcs considered.

This data collection is discussed in detail in the next chapter.

Model Formulation

This research model is implemented in LINDO™, a commercial linear programming software package. The model was described by 60 variables and 59 constraints. LINDO™ is capable of solving the discrete MILP material recovery facility location optimization problem proposed in this model. The model formulation is listed in detail in Appendix E.

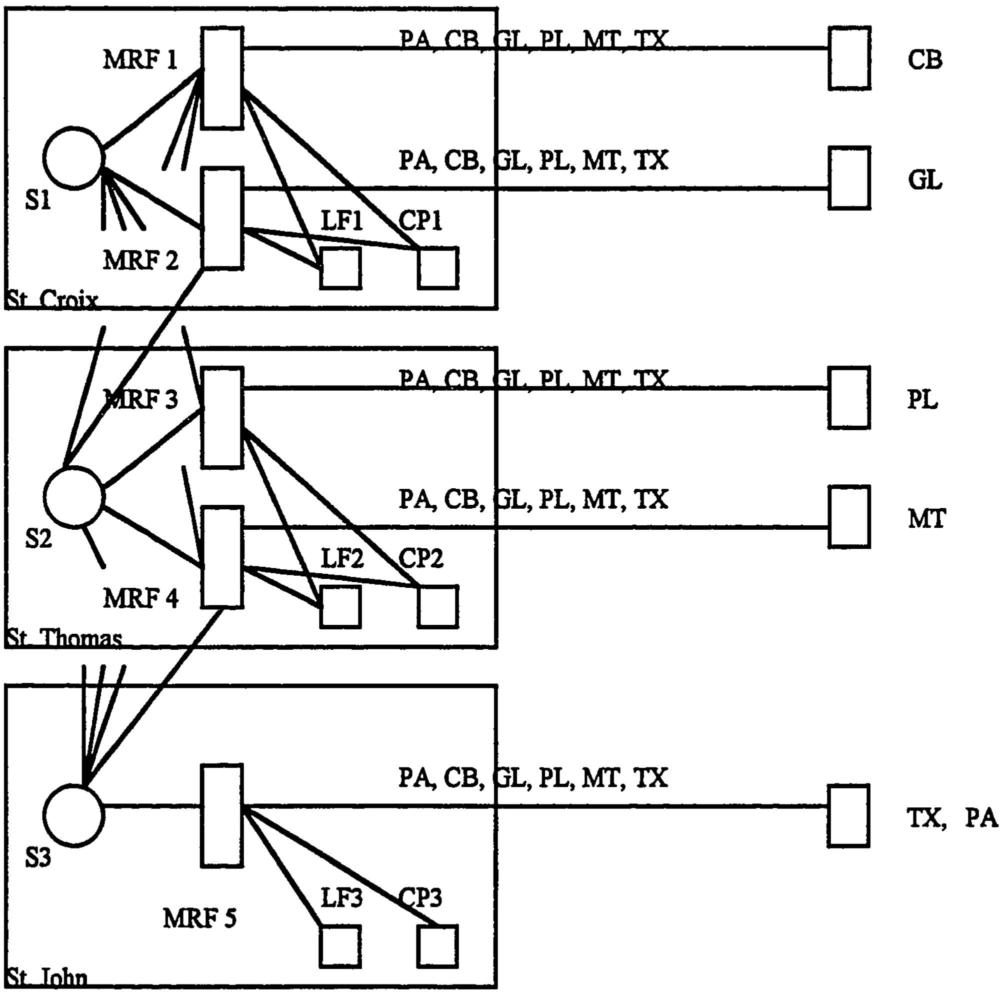

Figure 6. Illustrated Research Model Network

4. CASE STUDY MODEL AND SOLUTION

Data Collection

The data required for this research was collected from a variety of sources. The quantity of municipal waste generated in the U. S. Virgin Islands was collected from the waste characterization report conducted in 1992 and 1993 [GBB "Final Sort Report" 1994]. Quantities are provided for the year 1993 and projected for the years 1996, 2000 and 2005 based upon census projections on a per capita basis. The data includes the percentage of recoverable products in the waste stream. Cost of transportation was collected from the GBB "Report on Markets" (1994) and interviews. The report analyzed modes and costs of transportation from the Virgin Islands to markets in Puerto Rico, the United States and South America. Expected revenues from recovered products were also studied [GBB "Report on Markets" 1994]. The applicable data is summarized and discussed in the sections below and in Appendixes A through D. The CPRR Technical Report #71 contains a table of MRF sizes and the applicable capital and operating costs for the study area of the state of New Jersey. The table values were adjusted for this study by interpolation and extrapolation using additional data compiled from the following sources: Gershman et al. 1986; Lipták 1991; Swarzbaugh et al. 1993; Rogoff and Williams 1994; and the GBB "Report on Markets" 1994.

Municipal Solid Waste

Waste stream quantities and characterization by percentage of material in the waste stream for each island is provided in Appendix A. The selected information in tons per day (TPD) based upon a 260 operating day year is shown in Table 1.

Table 1. Municipal Solid Waste Projections (TPD).

	Year			
Island	1993	1996	2000	2005
St. Croix	405	428	459	490
St. Thomas	296	307	323	344
St. John	31	32	25	26
Total:	732	767	807	860

The solid waste management system designed must be able to process the total local waste stream for the individual island or the entire waste stream for all the islands. For instance, using 1993 waste quantities, the MRF in St.Croix must be sized to handle 405 TPD or 732 TPD. The MRFs considered are one medium and one large facility on each island except for St. John. The island is too small to support a larger facility. The MRF capacities in this study are listed in table 4-2.

Table 2. MRF Capacities Considered for Each Island

MRF 1:	St. Croix,	500 TPD	
MRF 2:	St. Croix,	800 TPD	
MRF 3:	St. Thomas,	300 TPD	(400 TPD for 1996 and beyond)
MRF 4:	St. Thomas,	800 TPD	
MRF 5:	St. John,	70 TPD	(smallest capacity evaluated)

MRF Capital and Operating Costs

MRF sorting technology can be tailored to projected waste streams. The literature contains many economic costs analysis methods, all based upon different assumptions, technologies and localities. For this study, capital and operating costs are estimated. Appendix B tabulates cost data for a set of MRFs of various capacities for each island considered. The data was derived from and formatted based upon the study conducted of New Jersey facilities by the CPRR. Data for MRF capacities not addressed in the study were derived from cost analysis of facilities in the planning or operating stages throughout the United States. Actual U. S. Virgin Islands building (per square foot) and land (per acre) costs for each individual island was utilized for this study. [CPRR Tech Report #71 1992; GBB "Reports on Markets" 1994; Swartzbaugh et al. 1993; Gershman et al. 1986; Virgin Islands Industrial Development Commission Business Guide 1992].

Cost of Transportation

Current waste collection involves centrally located refuse bins, either dumpster-type or of the roll on/roll off type. Bin sizes are 20 or 30 cubic yards. When full, these bins are transported directly to the landfill. Hauling rates range between $100 - 135 per trip on St. Croix, depending on the distance to the landfill. The island is only 26 miles in length and 6 miles wide at its widest point. The average is about $115. St. Thomas' rates are about 15% less and quantity hauled is slightly less per trip. St. John's rates are comparable to St. Thomas [Beagles 1994; Willocks 1994].

Assuming an average refuse density of 200 lb/yd^3 [Swartbaugh et al. 1993], and assuming an average full bin capacity of 30 cubic yards (6000 pounds) for St.Croix and about 28 cubic yards (5600 lbs) for St. Thomas and St. John, the on-island transportation costs are illustrated in Table 3 and summarized in Appendix C.

Table 3: On-Island Transportation Costs

St. Croix	\$115/trip	÷	3.0 tons/trip	=	\$38.33/ton
St. Thomas	\$ 98/trip	÷	2.8 tons/trip	=	\$35.00/ton
St. John	\$ 98/trip	÷	2.8 tons/trip	=	\$35.00/ton

For this research model, the transportation costs for St. Croix was rounded up to \$40/ton of MSW.

Barge transportation rates between the islands range between \$15-20 per ton down to \$3500/day for a 2200 ton capacity ocean barge or \$6000/day for a 5000 ton capacity barge. These charges exclude the cost of a pilot, various operating fees and duties [GBB "Report on Markets" 1994; Rogers 1994]. For modeling purposes, the value of \$15/ton is accepted between St. Croix and St. Thomas. Handling charges are unknown because a solid waste transportation infrastructure did not exist. A value of \$5/ton is accepted between St. Thomas and St. John because of the shorter distance and an existing solid waste transportation infrastructure.

Recovered Product Shipment to Markets

The cost of transportation to distant markets depends on the quantity of product shipped and the method of shipment. Selected recovered product shipping costs and revenues are illustrated in Tables 4 and 5. The data was derived from the market analysis report and summarized in Appendix D [GBB "Report on Markets" 1994].

Table 4. Recovered Products Shipping Costs

Paper:	none recovered
OCC:	40' container, 22 tons net, baled
	$1346 including customs to Puerto Rico
	or $61.18/ton
Plastics:	PET and HDPE recovered
	40' container, 17.4 tons baled (estimated)
	$1346 including customs to Puerto Rico
	or $77.27/ton
Glass:	color separated, crushed; 40' container, 22 tons
	$1300 including customs to Puerto Rico
	or $59.09/ton
Metals:	Ferrous and aluminum (example only)
	Aggregate composition: 74% ferrous, 18.8% alum
	Ferrous: 40' container, 22 tons, $1346
	Aluminum: 40' container, 15 tons bailed, $1560
	Aggregate total: $64.83/ton
Textiles:	clothes, rags, linen; 40' container, 20 tons
	$40 per container
	add $310 for handling for total of $350
	or $15.91/ton
Residue and compost:	
	$40.00 per ton for St. Croix
	$35.00 per ton for St. Thomas/St. John

Table 5. Revenue From Sale of Products at Market

Paper:	none recovered
OCC:	$40 per ton FOB delivery point Puerto Rico
Plastic:	PET and HDPE only
	$60 per ton FOB delivery point continental U. S.
Glass:	approx. $60 per ton FOB delivery point (high estimate)
Metals:	Ferrous and aluminum (example only)
	$20 per ton ferrous, $600 per ton alum
	Aggregate metal total: $127.60 per ton
Textiles:	$20 per ton FOB delivery point
Residue:	none
Compost:	approximately $20 ton for this model

Test scenarios

Decision makers would like to know how many MRF's should be built in the region, what size MRF to build and how changes in the projected waste stream affect the optimum system configuration. For this study, several scenarios are proposed for "what if" simulations. The scenarios chosen for analysis are:

Scenario 1a: Assign one MRF per island. Run model using year 1993 solid waste quantity data.

Scenario 1b: Relax the one MRF per island restriction. Run model using year 1993 solid waste quantity data.

Scenario 2a: Assign one MRF per island. Run model using year 1996 projected solid waste quantity data.

Scenario 2b: Relax the one MRF per island restriction. Run model using year 1996 projected solid waste quantity data.

Scenario 3a: Assign one MRF per island. Run model using year 2000 projected solid waste quantity data.

Scenario 3b: Relax the one MRF per island restriction. Run model using year 2000 projected solid waste quantity data.

Scenario 4a: Assign one MRF per island. Run model using year 2005 projected solid waste quantity data.

Scenario 4b: Relax the one MRF per island restriction. Run model using year 2005 projected solid waste quantity data.

Additional assumptions are discussed below:

a. The inflation rate is assumed to affect all costs by the same factor. Therefore, costs in all scenarios are expressed in constant, 1993 baseline dollars.

b. The LINDO™ LP software package used to solve these scenarios does not tolerate well an extreme range of coefficient values. The difference between the large capital costs of facility construction and the small recovery factors in this model formulation is approximately 1 x 10^8. In order to preclude potential significant errors in the solution, the estimated capital costs of construction is divided by 260, the estimated number of plant operating days per year. This correction reduces the coefficient range by two orders of magnitude, yet does not alter the optimum solution. Actual construction costs can be found by inspection of the tabulated facility data in Appendix B.

5. DISCUSSION AND ANALYSIS

There are two models developed: a) scenarios constrained by the requirement to site one MRF per island, and b) scenarios where the one MRF per island restriction was relaxed, allowing the model to select the optimum configuration. These models were then used for the scenarios discussed with different data sets for different years. Use of the forecasted solid waste quantities for future years was to analyze if there would be any changes from the current facility location decision by scenario 1a and scenario 1b. In the following sections, results from the models for given scenarios are discussed.

Scenario 1a : One MRF per island, year 1993 solid waste quantity data.

The results of this analysis shows solid waste flows from each island to the MRF selected on that island. Capital costs of $22.66 million reflect MRF construction for all facilities. Transportation and operating costs of $63,299 per day do not include inter-island modes. Total solid waste quantity is 732 tons per day (TPD). The network configuration result is outlined in Figure 7. System costs are summarized in Table 6.

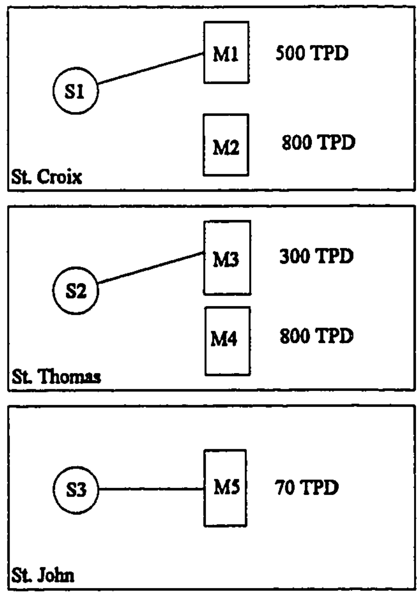

Figure 7. Scenario 1a Network Configuration

Table 6. One MRF Per Island, Year 1993 Solid Waste Quantity Data

Configuration -	M1, M3, M5
Solid waste flow -	S1M1, S2M3, S3M5
Capital construction costs -	$ 22.66 million
Operating and transportation costs -	$ 50,766 per day
Net product marketing costs -	$ 12,463 per day
Total operating cost -	$ 63,229 per day

Scenario 1b: One MRF per island restriction relaxed, year 1993 solid waste quantity data.

The results of this analysis shows a single large MRF selected on the island of St. Croix. Capital construction costs are reduced to $12.9 million. All solid waste streams from the territory flow through this facility. Transportation and operating costs increase to $ 68,806 per day, which includes inter-island flow of solid waste from the islands of St.

Thomas and St. John. The network configuration result is outlined in Figure 8. System costs are summarized in Table 7.

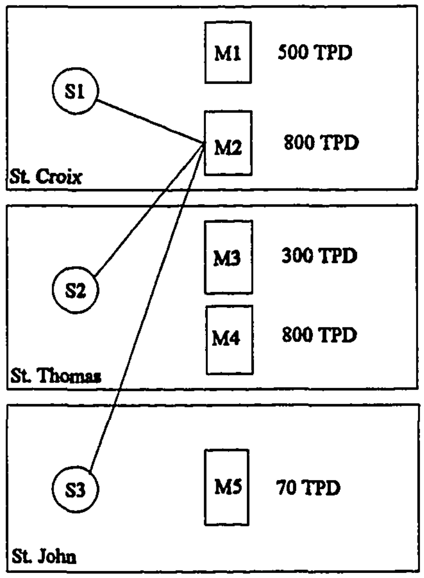

Figure 8. Scenario 1b Network Configuration

Table 8. One MRF Per Island Relaxed, Year 1993 Solid Waste Quantity Data.

Configuration -	M2
Solid waste flow -	S1M2, S2M2, S3M2
Capital construction costs -	$ 12.9 million
Operating and transportation costs -	$ 56,343 per day
Net product marketing costs -	$ 12,463 per day
Total operating cost -	$ 68,806 per day

Scenario 2a: One MRF per island, year 1996 solid waste quantity data.

The results of this analysis shows solid waste flow from each island to the MRF selected on that island. Capital costs of $ 26.34 million reflect MRF construction for all facilities. Transportation and operating costs of \$ 68,214 per day do not include inter-island modes. Total solid waste quantity is 767 TPD. The network configuration is the same as in scenario 1a. System costs are summarized in Table 8.

Table 8. One MRF Per Island, Year 1996 Solid Waste Quantity Data

Configuration -	M1, M3, M5
Solid waste flow -	S1M1, S2M3, S3M5
Capital construction costs -	\$ 26.34 million
Operating and transportation costs -	\$ 55,155 per day
Net product marketing costs -	\$ 13,059 per day
Total operating cost -	\$ 68,214 per day

Scenario 2b: One MRF per island restriction relaxed, year 1996 solid waste quantity data.

The results of this analysis was similar to scenario 1b. A single large MRF was selected on the island of St. Croix. Capital costs is reduced to \$ 12.9 million for the single facility. The entire solid waste stream from the territory flows through this facility. Transportation and operating costs increase to \$ 72,041 per day, which includes inter-island flow of solid waste from the islands of St. Thomas and St. John. The network configuration result is outlined in Figure 9. System costs are summarized in Table 9.

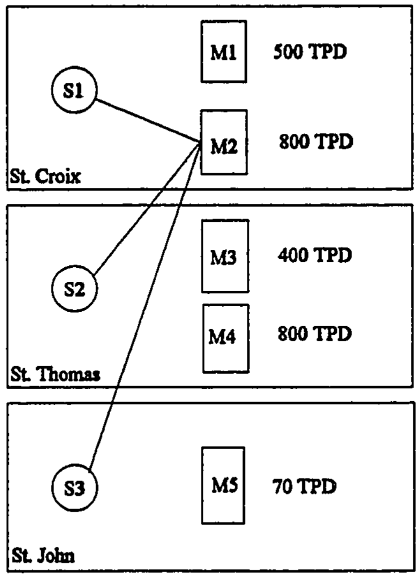

Figure 9. Scenario 2b Network Configuration

Table 9. One MRF Per Island Relaxed, Year 1993 Solid Waste Quantity Data.

Configuration -	M2
Solid waste flow -	S1M2, S2M2, S3M2
Capital construction costs -	$ 12.9 million
Operating and transportation costs -	$ 58,982 per day
Net product marketing costs -	$ 13,059 per day
Total operating cost -	$ 72,041 per day

Scenario 3a: One MRF per island, year 2000 solid waste quantity data.

The results of this computer run shows solid waste flows from each island to the MRF selected on that island. Capital costs of $ 26.34 million reflect MRF construction costs for all facilities. Transportation and operating costs of $ 71,629 per day do not include inter-island modes. Network configuration is similar to scenario 1a. System costs are summarized in Table 10.

Table 10. One MRF Per Island, Year 2000 Solid Waste Quantity Data

Configuration -	M1, M3, M5
Solid waste flow -	S1M1, S2M3, S3M5
Capital construction costs -	$ 26.34 million
Operating and transportation costs -	$ 57,889 per day
Net product marketing costs -	$ 13,740 per day
Total operating cost -	$ 71,629 per day

Scenario 3b: One MRF per island restriction relaxed, year 2000 solid waste quantity data.

The total solid waste quantity projected for the territory is 807 TDP, 7 TPD greater than the capacity of the largest MRF evaluated. This created a situation where the solution is not intuitively obvious or one that could be solved by direct inspection. The optimum configuration for this set of data are two MRF's, one located on the island St. Croix and the other on the island of St. John. Total capital cost is $ 15.6 million. The solid waste stream from the islands of St. Croix and St. Thomas flow to the MRF on St. Croix. The solid waste stream from St. John is handled by the MRF of that island. Transportation and operating costs increase to $ 75,679 per day, which includes inter-island flow of solid waste from the island of St. Thomas to St. Croix. The network configuration result is outlined in Figure 10. System costs are summarized in Table 11.

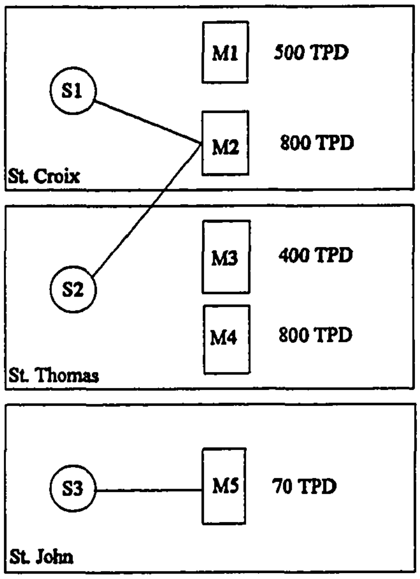

Figure 10. Scenario 3b Network Configuration

Table 11. One MRF Per Island Relaxed, Year 2000 Solid Waste Quantity Data

Configuration -	M2, M5
Solid waste flow -	S1M2, S2M2, S3M5
Capital construction costs -	$ 15.6 million
Operating and transportation costs -	$ 61,939 per day
Net product marketing costs -	$ 13,740 per day
Total operating cost -	$ 75,679 per day

Scenario 4a: One MRF per island, year 2005 solid waste quantity data.

The results of this computer run shows solid waste flows from each island to the MRF selected on that island. Capital costs of $ 26.34 million reflect MRF construction costs for all three facilities. Transportation and operating costs do not include inter-island modes. Network configuration is similar to scenario 1b. System costs are summarized in Table 12.

Table 12. One MRF Per Island, 2005 Solid Waste Quantity Data

Configuration -	M1, M3, M5
Solid waste flow -	S1M1, S2M3, S3M5
Capital construction costs -	$ 26.34 million
Operating and transportation costs -	$ 61,079 per day
Net product marketing costs -	$ 14,643 per day
Total operating cost -	$ 76,322 per day

Scenario 4b: One MRF per island restriction relaxed, year 2005 solid waste quantity data.

This scenario result was similar to the year 2000 data (scenario 3b) in that the solid waste quantity projected for the entire territory is 860 TDP, 60 TPD greater than the capacity of the largest MRF evaluated. The optimum configuration for this set of data is similar to scenario 3b: two MRF's, one located on the island St. Croix and the other on the island of St. John. Total capital cost is $ 15.6 million. The solid waste stream from the islands of St. Croix and St. Thomas flow to the MRF on St. Croix. The solid waste stream from St. John is handled by the MRF on that island. Transportation and operating costs increase to $ 80,871 per day, including inter-island transportation modes. There is one major difference between this scenario and scenario 3b: solid waste stream flow from the island of St. Thomas to St. John. The explanation was determined from inspection of the quantities of solid waste flows. The best solution selected a total MRF capacity of 870 TPD, which closely matched the 860 TPD territorial solid waste stream. The network configuration result is outlined in Figure 11. System costs are summarized in Table 13.

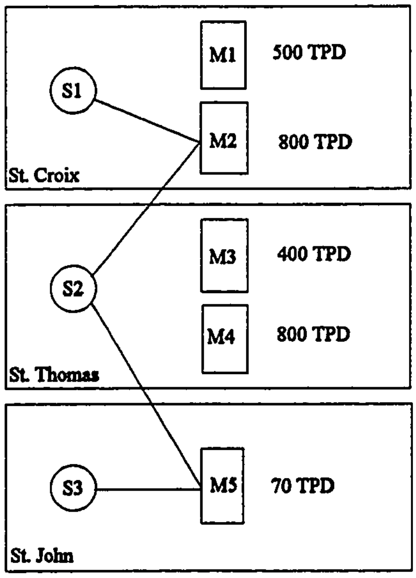

Figure 11. Scenario 4b Network Configuration

Table 13. One MRF Per Island Relaxed, Year 2005 Solid Waste Quantity Data

Configuration -	M2, M5
Solid waste flow -	S1M2, S2M2, S2M5, S3M5
Capital construction costs -	$ 15.6 million
Operating and transportation costs -	$ 66,228 per day
Net product marketing costs -	$ 14,643 per day
Total operating cost -	$ 80,871 per day

Comparison of Scenarios and Recommendations

The scenarios were selected as a simulation of the alternatives that a typical municipal would be expected to analyze in the course of determining a solid waste strategy that considered the growth in solid waste quantity generated. It was determined that as the solid waste quantity increased, the optimum configuration of the system changed. The capital cost of MRF construction and the daily operating costs are summarized in Table 14 below:

Table 14. Summary of Capital and Operating Costs for Each Configuration

		Year			
Scenario:	**Costs**	1993	1996	2000	2005
One MRF per island restriction (1a, 2a, 3a, 4a)	Capital	$ 22.66M	$ 26.34M	$ 26.34M	$ 26.34M
	Transport and Operations	$ 63,229	$ 68,214	$ 71,629	$ 76,322
Relaxed restriction (1b, 2b, 3b, 4b)	Capital	$ 12.9M	$ 12.9M	$ 15.6M	$ 15.6M
	Transport and Operations	$ 68,806	$ 72,041	$ 75,679	$ 80,871

In all cases, the capital cost of the relaxed configuration was significantly less than the one MRF per island configuration. The average reduction was approximately 44%. That reduction is accompanied by a relatively small increase in daily operating costs due to higher transportation costs. The average increase in operating costs was 6.5%. The cost differentials are summarized below in Table 15.

Table 15. Percent Cost Difference Between Constrained and Relaxed Configurations (Scenarios 1a thru 4a and 1b thru 4b)

Year:	1993	1996	2000	2005
Capital outlay cost	-43.10%	-51.00%	-40.80%	-40.80%
Daily operating costs	8.82%	5.61%	5.65%	5.96%

If the objective of decision makers is to build material recovery facilities in the U.S. Virgin Islands, two alternative recommendations can be made based upon the results of the analysis above:

1. Build one 800 TPD capacity material recovery facility now in St. Croix to handle the solid waste stream from all three islands. As the solid waste stream quantity increases, build a second facility of 70 TPD capacity in St. John to handle that island's projected solid waste.
2. Consider building a facility of greater capacity than 800 TPD in St. Croix now and avoid the cost of constructing a second facility in the future.

In either case, decision makers can use the information derived from these scenarios to determine appropriate land and building costs and financing and transportation rates, other than those assumed in this research, potentially reducing the operating costs of the single-facility configuration. Further, operating and maintenance costs factors over the life of the MRF can be incorporated into the model as more specific data on facility design becomes available.

6. CONCLUSIONS AND FUTURE RESEARCH

Conclusions

The application of a facilities location model in the context of a system of island communities separated by miles of ocean was proposed and studied in this research. A review of the body of knowledge in facility location theory and the successful application of facility location models to the study of continental municipal facilities planning alternatives, suggested that these methods could be applied to a system of islands. In this research, the islands are viewed from a regional perspective, as opposed to the fragmented approach normally associated with planning services for these communities.

In this study, a mixed-integer linear programming model is proposed and developed that incorporated the transportation infrastructure between the islands into the overall system design. A management decision process to select the best configuration for a solid waste management system was simulated by the analysis of four location scenarios with varying sizes of facilities. In this fashion, the benefits of the economy of scale associated with larger facilities was investigated.

The successful application of existing facilities location models to the problem of regional solid waste management within a group of dispersed islands was completed in this study. A hypothetical system of material recovery facilities (MRF) for the U. S. Virgin Islands was studied to determine the optimum transportation network structure between an aggregated island solid waste stream and a proposed set of MRFs. Actual and projected solid waste quantities are collected from the literature. The model developed was applied to typical MRF construction and operating costs, adjusted for local land and building costs, and local transportation costs, of which data was available in the literature or estimated.

It is concluded that the regional viewpoint to municipal planning can result in significant reductions in capital expenditures for facility construction. The planning scenarios studied show an average of 44% reduction in capital costs and in two cases, eliminated the requirement for two of three facilities. The reduction in the number of facilities is accomplished with an associated increase the costs of transporting solid waste between the islands. This was expected, in part due to the higher than average costs assumed in the research. However, the scenarios studied show this increase is small, averaging 6.5% for all scenarios studied. Based upon the research, the following recommendations are suggested: a) build one 800 TPD capacity facility now on the island of St. Croix to handle the solid waste stream from all three islands. As the solid waste stream quantity increases, build a second facility of 70 TPD capacity in St. John to handle that island's projected solid waste. Or b) consider building a facility of greater capacity than 800 TPD in St. Croix now and avoid the cost of constructing a second facility in the future.

Considering the results reported from this research, a regional approach to planning in the Caribbean and other systems of islands is justified. This research has contributed to the body of knowledge in solid waste management where a void existed in the study of the incorporation of an ocean transportation infrastructure into regional facilities planning. As continental municipalities increasingly enjoy the benefits of regional solid waste management systems, this study confirms that island communities can also enjoy the identical benefits not afforded with a continued fragmented facilities planning approach.

Future Research

The results of this research will be made available to the Department of Public Works of the Virgin Islands to assist in their solid waste planning process. Depending on their needs, the basic model can be modified and expanded to include all the necessary factors that they consider important.

Similarly, research into the application of this model to a much larger system of islands, the entire chain of Caribbean islands, for instance, should be conducted to determine if the regional viewpoint toward solid waste management remains valid. Data required for such a study would be similar to that obtained for the research previously conducted, to include:

- comprehensive solid waste characterization for all islands in the study area,
- a candidate set of facility location sites,
- specific demand locations, as opposed to the aggregated demand location in the research model, and
- mode specific transportation costs for all sources and destinations of solid waste and recovered products.

Further, a comprehensive model should incorporate stochastic analysis of the data noted above, as well as MSW stream quantities, MRF capacity and daily and other operating factors appropriate to the level of accuracy required.

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APPENDIX A

Waste Quantity Generated

Island	Year	1993	1994	1995	1996	1997	1998	1999	2000	2005
St. Croix		105,390	107,287	109,217	111,182	113,182	115,218	117,291	119,401	127,373
St. Thomas		77,018	77,964	78,921	79,921	80,933	81,959	82,997	84,049	89,496
St. John		8,030	8,228	5,797	8,435	6,229	6,307	6,387	6,468	6,888
	Tot TPY:	190,438	193,479	193,935	199,538	200,344	203,484	206,675	209,918	223,757
St. Croix		405	413	420	428	435	443	451	459	490
St. Thomas		296	300	304	307	311	315	319	323	344
St. John		31	32	22	32	24	24	25	25	26
	Tot TPD:	732	744	746	767	771	783	795	807	861

Data summarized from Table II-1 of the GBB Final Sort Report: Waste Characterization Analysis (1994)

Material Recovery Facility Sort Capability

Product	Island	% in MSW	% recvrd	Tot % rec	% cpst	Tot % cpst	% residue	Tot % LF
Paper:	St. Croix	15.40%	0.00%	0.00%	90.00%	13.86%	10.00%	1.54%
	St. Thomas	15.97%	0.00%	0.00%	90.00%	14.37%	10.00%	1.60%
	St. John	10.97%	0.00%	0.00%	90.00%	9.87%	10.00%	1.10%
OCC:	St. Croix	12.78%	50.00%	6.39%	40.00%	5.11%	10.00%	1.28%
	St. Thomas	11.45%	50.00%	5.73%	40.00%	4.58%	10.00%	1.15%
	St. John	17.36%	50.00%	8.68%	40.00%	6.94%	10.00%	1.74%
Plastics:	St. Croix	8.18%	19.00%	1.55%	4.00%	0.33%	77.00%	6.30%
	St. Thomas	8.39%	19.00%	1.59%	4.00%	0.34%	77.00%	6.46%
	St. John	5.40%	19.00%	1.03%	4.00%	0.22%	77.00%	4.16%
Glass:	St. Croix	12.61%	50.00%	6.31%	10.00%	1.26%	40.00%	5.04%
	St. Thomas	11.01%	50.00%	5.51%	10.00%	1.10%	40.00%	4.40%
	St. John	9.77%	50.00%	4.89%	10.00%	0.98%	40.00%	3.91%
Metals:	St. Croix	7.54%	79.00%	5.96%	0.00%	0.00%	21.00%	1.58%
	St. Thomas	6.57%	79.00%	5.19%	0.00%	0.00%	21.00%	1.38%
	St. John	13.77%	79.00%	10.88%	0.00%	0.00%	21.00%	2.89%
Organics:	St. Croix	41.55%	6.00%	2.49%	72.00%	29.92%	22.00%	9.14%
	St. Thomas	45.28%	6.00%	2.72%	72.00%	32.60%	22.00%	9.96%
	St. John	39.92%	6.00%	2.40%	72.00%	28.74%	22.00%	8.78%
Misc.:	St. Croix	1.92%	0.00%	0.00%	0.00%	0.00%	100.00%	1.92%
	St. Thomas	1.27%	0.00%	0.00%	0.00%	0.00%	100.00%	1.27%
	St. John	2.83%	0.00%	0.00%	0.00%	0.00%	100.00%	2.83%

Tot % cpst	St. Croix	50.48%	**Tot % LF**	St. Croix	26.81%
	St. Thomas	52.99%		St. Thomas	26.22%
	St. John	46.75%		St. John	25.40%

APPENDIX B

MRF_STX

Material Recovery Facility: St. Croix Island

	Capacity:								
Tons per Year (TPY)	18,200	26,000	52,000	78,000	104,000	130,000	156,000	182,000	208,000
Tons per Day (TPD)	70	100	200	300	400	500	600	700	800
Capital Costs									
Square feet required:	12,000	25,000	35,000	50,000	52,500	55,000	60,000	65,000	70,000
Number of acres required:	2	4	3.5	6	5	4	4.5	5	6
Building cost @ $100/sqf	1,200,000	2,500,000	3,500,000	5,000,000	5,250,000	5,500,000	6,000,000	6,500,000	7,000,000
Land @ $150k/acre	300,000	600,000	525,000	900,000	750,000	600,000	675,000	750,000	900,000
Equipment	700,000	1,000,000	2,000,000	3,000,000	3,250,000	3,500,000	4,000,000	4,500,000	5,000,000
Total:	2,200,000	4,100,000	6,025,000	8,900,000	9,250,000	9,600,000	10,675,000	11,750,000	12,900,000
Per TPD	8,462	15,769	23,173	34,231	35,577	36,923	41,058	45,192	49,615
Capital and Depreciation	Costs								
Building Depr (25 yrs)	48,000	100,000	140,000	200,000	210,000	220,000	240,000	260,000	280,000
Debt Service 10%	120,000	250,000	350,000	500,000	525,000	550,000	600,000	650,000	700,000
Land debt 10%	30,000	60,000	52,500	90,000	75,000	60,000	67,500	75,000	90,000
Equip Depr 14.3%	100,100	143,000	286,000	429,000	464,750	500,500	572,000	643,500	715,000
Equip Debt 6%	42,000	60,000	120,000	180,000	195,000	210,000	240,000	270,000	300,000
Total:	340,100	613,000	948,500	1,399,000	1,469,750	1,540,500	1,719,500	1,898,500	2,085,000
Variable Costs									
Util & Maint	100,000	130,000	261,000	390,000	520,000	650,000	780,000	909,000	1,039,000
Labor	416,000	483,600	985,000	572,000	1,884,000	1,612,000	2,132,000	2,652,000	3,172,000
Total:	516,000	613,600	1,246,000	962,000	2,404,000	2,262,000	2,912,000	3,561,000	4,211,000
Operating Costs:	47.04	47.18	42.20	30.27	37.25	29.25	29.69	30.00	30.27

MRF_STT

Material Recovery Facility: **St. Thomas Island**

	Capacity:								
Tons per Year (TPY)	18200	26000	52000	78000	104000	130000	156000	182000	208000
Tons per Day (TPD)	70	100	200	**300**	**400**	500	600	700	**800**
Capital Costs									
Square feet required:	12,000	25,000	35,000	50,000	52,500	55,000	60,000	65,000	70,000
Number of acres required:	2	4	3.5	6	5	4	4.5	5	6
Building cost @ $125/sqft	1,500,000	3,125,000	4,375,000	6,250,000	6,562,500	6,875,000	7,500,000	8,125,000	8,750,000
Land @ $185k/acre	370,000	740,000	647,500	1,110,000	925,000	740,000	832,500	925,000	1,110,000
Equipment	700,000	1,000,000	2,000,000	3,000,000	3,250,000	3,500,000	4,000,000	4,500,000	5,000,000
Total:	2,570,000	4,865,000	7,022,500	**10,360,000**	**10,737,500**	11,115,000	12,332,500	13,550,000	**14,860,000**
Per TPD	9,885	18,712	27,010	39,846	41,298	42,750	47,433	52,115	57,154
Capital and Depreciation Costs									
Building Depr (25 yrs)	60,000	125,000	175,000	250,000	262,500	275,000	300,000	325,000	350,000
Debt Service 10%	150,000	312,500	437,500	625,000	656,250	687,500	750,000	812,500	875,000
Land debt 10%	37,000	74,000	64,750	111,000	92,500	74,000	83,250	92,500	111,000
Equip Depr 14.3%	100,100	143,000	286,000	429,000	464,750	500,500	572,000	643,500	715,000
Equip Debt 6%	42,000	60,000	120,000	180,000	195,000	210,000	240,000	270,000	300,000
Total:	389,100	714,500	1,083,250	1,595,000	1,671,000	1,747,000	1,945,250	2,143,500	2,351,000
Variable Costs									
Util & Maint	100,000	130,000	261,000	390,000	520,000	650,000	780,000	909,000	1,039,000
Labor	416,000	483,600	985,000	572,000	1,884,000	1,612,000	2,132,000	2,652,000	3,172,000
Total:	516,000	613,600	1,246,000	962,000	2,404,000	2,262,000	2,912,000	3,561,000	4,211,000
Operating Costs:	49.73	51.08	44.79	**32.78**	**39.18**	30.84	31.14	31.34	**31.55**

MRF_STJ

Material Recovery Facility: **St. John Island**

	Capacity:								
Tons per Year (TPY)	18200	26000	52000	78000	104000	130000	156000	182000	208000
Tons per Day (TPD)	70	100	200	300	400	500	600	700	800
Capital Costs									
Square feet required:	12,000	25,000	35,000	50,000	52,500	55,000	60,000	65,000	70,000
Number of acres required:	2	4	3.5	6	5	4	4.5	5	6
Building cost @ $135/sqf	1,620,000	3,375,000	4,725,000	6,750,000	7,087,500	7,425,000	8,100,000	8,775,000	9,450,000
Land @ $190k/acre	380,000	760,000	665,000	1,140,000	950,000	760,000	855,000	950,000	1,140,000
Equipment	700,000	1,000,000	2,000,000	3,000,000	3,250,000	3,500,000	4,000,000	4,500,000	5,000,000
Total:	2,700,000	5,135,000	7,390,000	10,890,000	11,287,500	11,685,000	12,955,000	14,225,000	15,590,000
Per TPD	10,385	19,750	28,423	41,885	43,413	44,942	49,827	54,712	59,962
Capital and Depreciation	Costs								
Building Depr (25 yrs)	64,800	135,000	189,000	270,000	283,500	297,000	324,000	351,000	378,000
Debt Service 10%	162,000	337,500	472,500	675,000	708,750	742,500	810,000	877,500	945,000
Land debt 10%	38,000	76,000	66,500	114,000	95,000	76,000	85,500	95,000	114,000
Equip Depr 14.3%	100,100	143,000	286,000	429,000	464,750	500,500	572,000	643,500	715,000
Equip Debt 6%	42,000	60,000	120,000	180,000	195,000	210,000	240,000	270,000	300,000
Total:	406,900	751,500	1,134,000	1,668,000	1,747,000	1,826,000	2,031,500	2,237,000	2,452,000
Variable Costs									
Util & Maint	100,000	130,000	261,000	390,000	520,000	650,000	780,000	909,000	1,039,000
Labor	416,000	483,600	985,000	572,000	1,884,000	1,612,000	2,132,000	2,652,000	3,172,000
Total:	516,000	613,600	1,246,000	962,000	2,404,000	2,262,000	2,912,000	3,561,000	4,211,000
Operating Costs:	50.71	52.5	45.77	33.72	39.91	31.45	31.69	31.86	32.03

APPENDIX C

Variable costs per TPD of MSW processed at MRF (j)

Source	Dest	Trans$	Var MRF$	Total Costs (TR+VAR)	Variable Name
S1	M1	$40.00	$29.25	$69.25	S1M1
S1	M2	$40.00	$30.27	$70.27	S1M2
S1	M3	$55.00	$32.78	$87.78	S1M3 (1993)
S1	M3	$55.00	$39.18	$94.18	S1M3 (1996 on)
S1	M4	$55.00	$31.55	$86.55	S1M4
S1	M5	$55.00	$50.71	$105.71	S1M5
S2	M1	$55.00	$29.25	$84.25	S2M1
S2	M2	$55.00	$30.27	$85.27	S2M2
S2	M3	$35.00	$32.78	$67.78	S2M3 (1993)
S2	M3	$35.00	$39.18	$74.18	S2M3 (1996 on)
S2	M4	$35.00	$31.55	$66.55	S2M4
S2	M5	$40.00	$50.71	$90.71	S2M5
S3	M1	$55.00	$29.25	$84.25	S3M1
S3	M2	$55.00	$30.27	$85.27	S3M2
S3	M3	$40.00	$32.78	$72.78	S3M3 (1993)
S3	M3	$40.00	$39.18	$79.18	S3M3 (1996 on)
S3	M4	$40.00	$31.55	$71.55	S3M4
S3	M5	$35.00	$50.71	$85.71	S3M5

Legend:

S1 = STX (St. Croix)
S2 = STT (St. Thomas)
S3 = STJ (St. John)

M1 = 500 TPD MRF, STX
M2 = 800 TPD MRF, STX
M3 = 300 TPD MRF, STT (400 TPD for year 1996, 2000 and 2005 MSW quantity data)
M4 = 800 TPD MRF, STT
M5 = 70 TPD MRF, STJ

APPENDIX D

Legend:

MRFs:

M1 = 500 TPD facility on St. Croix
M2 = 800 TPD facility on St. Croix
M3 = 300 TPD facility on St. Thomas (for 1993 scenario)
400 TPD facility on St. Thomas (for 1996, 2000 and 2005 scenarios)
M4 = 800 TPD facility on St. Thomas
M5 = 70 TPD facility on St. John

Notes:
1. Net transportation costs for recovered products.
2. Weighed recovery factor for each product.
3. Model variable name.

Paper (PA):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1	$0.00	$0.00	$0.00	0.000	M1PA
M2	$0.00	$0.00	$0.00	0.000	M2PA
M3	$0.00	$0.00	$0.00	0.000	M3PA
M4	$0.00	$0.00	$0.00	0.000	M4PA
M5	$0.00	$0.00	$0.00	0.000	M5PA

Old Corrugated Cardboard (CB):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1	$61.18	$40.00	$21.18	0.062	M1CB
M2	$61.18	$40.00	$21.18	0.062	M2CB
M3	$61.18	$40.00	$21.18	0.062	M3CB
M4	$61.18	$40.00	$21.18	0.062	M4CB
M5	$61.18	$40.00	$21.18	0.062	M5CB

Plastics (PL):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1	$77.27	$60.00	$17.27	0.015	M1PL
M2	$77.27	$60.00	$17.27	0.015	M2PL
M3	$77.27	$60.00	$17.27	0.015	M3PL
M4	$77.27	$60.00	$17.27	0.015	M4PL
M5	$77.27	$60.00	$17.27	0.015	M5PL

Glass (GL):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1	$59.09	$60.00	($0.91)	0.059	M1GL
M2	$59.09	$60.00	($0.91)	0.059	M2GL
M3	$59.09	$60.00	($0.91)	0.059	M3GL
M4	$59.09	$60.00	($0.91)	0.059	M4GL
M5	$59.09	$60.00	($0.91)	0.059	M5GL

Metals (MT):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1	$64.83	$127.60	($62.78)	0.059	M1MT
M2	$64.83	$127.60	($62.78)	0.059	M2MT
M3	$64.83	$127.60	($62.78)	0.059	M3MT
M4	$64.83	$127.60	($62.78)	0.059	M4MT
M5	$64.83	$127.60	($62.78)	0.059	M5MT

Textiles (TX):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1	$15.91	$20.00	($4.09)	0.026	M1TX
M2	$15.91	$20.00	($4.09)	0.026	M2TX
M3	$15.91	$20.00	($4.09)	0.026	M3TX
M4	$15.91	$20.00	($4.09)	0.026	M4TX
M5	$15.91	$20.00	($4.09)	0.026	M5TX

Landfill residue (LF):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1 → LF1	$40.00	$0.00	$40.00	0.265	M1LF1
M2 → LF1	$40.00	$0.00	$40.00	0.265	M2LF1
M3 → LF2	$35.00	$0.00	$35.00	0.265	M3LF2
M4 → LF2	$35.00	$0.00	$35.00	0.265	M4LF2
M5 → LF3	$35.00	$0.00	$35.00	0.265	M5LF3

Note: One landfill is located on each island. More than one facility can utilize a single landfill.

Compost (CP):

MRF	Trans	Revenue	Net cost	R_k-factor	Var_name
M1 → CP1	$40.00	$20.00	$20.00	0.514	M1CP1
M2 → CP1	$40.00	$20.00	$20.00	0.514	M2CP1
M3 → CP2	$35.00	$20.00	$15.00	0.514	M3CP2
M4 → CP2	$35.00	$20.00	$15.00	0.514	M4CP2
M5 → CP3	$35.00	$20.00	$15.00	0.514	M5CP3

Note: One compost facility is located on each island. More than one MRF can utilize a single compost facility.

APPENDIX E

```
bat
! Year 1993 Scenario 1a
!
 MIN    36923 Z1 + 49615 Z2 + 39846 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 87.78 S1M3 + 67.78 S2M3 + 72.78 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
      2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   405
      3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   296
      4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   31
      5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=   0
      6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=   0
      7) - 300 Z3 + S1M3 + S2M3 + S3M3 <=   0
      8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=   0
      9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=   0
     10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
     11)  M1CB + M2CB + M3CB + M4CB + M5CB <=   55
     12)  M1PL + M2PL + M3PL + M4PL + M5PL <=   20
     13)  M1GL + M2GL + M3GL + M4GL + M5GL <=   55
     14)  M1MT + M2MT + M3MT + M4MT + M5MT <=   55
     15)  M1TX + M2TX + M3TX + M4TX + M5TX <=   25
     16)  M1LF1 + M2LF1 <=   210
     17)  M3LF2 + M4LF2 <=   210
     18)  M5LF3 <=   20
     19)  M1CP1 + M2CP1 <=   410
     20)  M3CP2 + M4CP2 <=   410
     21)  M5CP3 <=   40
     22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
     23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
     24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
     25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
     26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
     27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
     28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
     29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
     30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
     31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
     32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
     33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
     34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
     35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
     36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
```

```
37) 0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =  0
38) 0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =  0
39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT =  0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT =  0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT =  0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX =  0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX =  0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX =  0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX =  0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX =  0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 =  0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 =  0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 =  0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 =  0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 =  0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 =  0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 =  0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 =  0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 =  0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 =  0
57) z1 = 1
58) z3 = 1
59) z5 = 1
END
INTE  5
leave
```

Scenario 1a

OBJECTIVE FUNCTION VALUE

1) 147901.60

VARIABLE	VALUE	REDUCED COST
Z1	1.000000	36923.000000
Z2	.000000	49615.000000
Z3	1.000000	39846.000000
Z4	.000000	56170.000000
Z5	1.000000	10385.000000
S1M1	405.000000	.000000
S2M1	.000000	20.480000
S3M1	.000000	79.144990
S1M2	.000000	1.020000
S2M2	.000000	21.500000
S3M2	.000000	80.164990
S1M3	.000000	14.670000
S2M3	296.000000	.000000
S3M3	.000000	64.069990
S1M4	.000000	14.670000
S2M4	.000000	.000000
S3M4	.000000	64.069990
S1M5	.000000	32.600000
S2M5	.000000	22.930000
S3M5	31.000000	.000000
M1CB	25.920000	.000000
M2CB	.000000	.000000
M3CB	16.872000	.000000
M4CB	.000000	.000000
M5CB	2.697000	.000000
M1PL	6.480000	.000000
M2PL	.000000	.000000
M3PL	4.736000	.000000
M4PL	.000000	.000000
M5PL	.310000	.000000
M1GL	25.515000	.000000
M2GL	.000000	.000000
M3GL	16.280000	.000000
M4GL	.000000	.000000
M5GL	1.519000	.000000
M1MT	24.300000	.000000
M2MT	.000000	.000000
M3MT	15.392000	.000000
M4MT	.000000	.000000
M5MT	3.379000	.000000
M1TX	10.125000	.000000
M2TX	.000000	.000000
M3TX	7.992000	.000000
M4TX	.000000	.000000
M5TX	.744000	.000000
M1LF1	108.135000	.000000
M2LF1	.000000	.000000
M3LF2	77.848010	.000000
M4LF2	.000000	.000000
M5LF3	7.874000	.000000

M1CP1	204.525000	.000000
M2CP1	.000000	.000000
M3CP2	159.544000	.000000
M4CP2	.000000	.000000
M5CP3	14.477000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-87.735460
3)	.000000	-83.128540
4)	.000000	-19.634590
5)	95.000000	.000000
6)	.000000	.000000
7)	4.000000	.000000
8)	.000000	1.229996
9)	39.000000	.000000
10)	.000000	.000000
11)	9.510999	.000000
12)	8.473999	.000000
13)	11.686000	.000000
14)	11.929000	.000000
15)	6.138999	.000000
16)	101.865000	.000000
17)	132.152000	.000000
18)	12.126000	.000000
19)	205.475000	.000000
20)	250.456000	.000000
21)	25.523000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000
57)	.000000	.000000
58)	.000000	.000000
59)	.000000	.000000

NO. ITERATIONS= 10
BRANCHES= 0 DETERM.= 1.000E 0

```
bat
! Year 1993 Scenario 1b
!
 MIN    36923 Z1 + 49615 Z2 + 39846 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 87.78 S1M3 + 67.78 S2M3 + 72.78 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
      2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   405
      3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   296
      4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   31
      5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=  0
      6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=  0
      7) - 300 Z3 + S1M3 + S2M3 + S3M3 <=  0
      8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=  0
      9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=  0
     10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
     11)  M1CB + M2CB + M3CB + M4CB + M5CB <=  55
     12)  M1PL + M2PL + M3PL + M4PL + M5PL <=  20
     13)  M1GL + M2GL + M3GL + M4GL + M5GL <=  55
     14)  M1MT + M2MT + M3MT + M4MT + M5MT <=  55
     15)  M1TX + M2TX + M3TX + M4TX + M5TX <=  25
     16)  M1LF1 + M2LF1 <=  210
     17)  M3LF2 + M4LF2 <=  210
     18)  M5LF3 <=  20
     19)  M1CP1 + M2CP1 <=  410
     20)  M3CP2 + M4CP2 <=  410
     21)  M5CP3 <=  40
     22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
     23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
     24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
     25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
     26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
     27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
     28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
     29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
     30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
     31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
     32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
     33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
     34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
     35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
     36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
     37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =   0
     38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =   0
```

39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT = 0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT = 0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT = 0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX = 0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX = 0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX = 0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX = 0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX = 0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 = 0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 = 0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 = 0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 = 0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 = 0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 = 0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 = 0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 = 0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 = 0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 = 0
END
INTE 5
leave

Scenario 1b

OBJECTIVE FUNCTION VALUE

1) 119624.80

VARIABLE	VALUE	REDUCED COST
Z1	.000000	36413.000000
Z2	1.000000	49615.000000
Z3	.000000	33396.000000
Z4	.000000	38970.010000
Z5	.000000	4773.451000
S1M1	.000000	.000003
S2M1	.000000	-.000005
S3M1	.000000	.000000
S1M2	405.000000	.000000
S2M2	296.000000	.000000
S3M2	31.000000	.000000
S1M3	.000000	35.150000
S2M3	.000000	.000000
S3M3	.000000	5.404997
S1M4	.000000	35.150000
S2M4	.000000	.000000
S3M4	.000000	5.404997
S1M5	.000000	111.745000
S2M5	.000000	81.595000
S3M5	.000000	.000000
M1CB	.000000	.000000
M2CB	45.489000	.000000
M3CB	.000000	.000000
M4CB	.000000	.000000
M5CB	.000000	.000000
M1PL	.000000	.000000
M2PL	11.526000	.000000
M3PL	.000000	.000000
M4PL	.000000	.000000
M5PL	.000000	.000000
M1GL	.000000	.000000
M2GL	43.314000	.000000
M3GL	.000000	.000000
M4GL	.000000	.000000
M5GL	.000000	.000000
M1MT	.000000	.000000
M2MT	43.071000	.000000
M3MT	.000000	.000000
M4MT	.000000	.000000
M5MT	.000000	.000000
M1TX	.000000	.000000
M2TX	18.861000	.000000
M3TX	.000000	.000000
M4TX	.000000	.000000
M5TX	.000000	.000000
M1LF1	.000000	.000000
M2LF1	193.857000	.000000
M3LF2	.000000	.000000
M4LF2	.000000	.000000
M5LF3	.000000	.000000

M1CP1	.000000	.000000
M2CP1	378.546000	.000000
M3CP2	.000000	.000000
M4CP2	.000000	.000000
M5CP3	.000000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-88.755460
3)	.000000	-104.628500
4)	.000000	-99.799590
5)	.000000	1.019997
6)	68.000000	.000000
7)	.000000	21.500000
8)	.000000	22.729990
9)	.000000	80.164990
10)	.000000	.000000
11)	9.510999	.000000
12)	8.473999	.000000
13)	11.686000	.000000
14)	11.929000	.000000
15)	6.138999	.000000
16)	16.143000	.000000
17)	210.000000	.000000
18)	20.000000	.000000
19)	31.454010	.000000
20)	410.000000	.000000
21)	40.000000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000

```
NO. ITERATIONS=      32
BRANCHES=     2 DETERM.=  1.000E    0
```

```
bat
! Year 1996 Scenario 2a
!
 MIN    36923 Z1 + 49615 Z2 + 41298 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 94.18 S1M3 + 74.18 S2M3 + 79.18 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
      2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   428
      3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   307
      4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   32
      5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=  0
      6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=  0
      7) - 400 Z3 + S1M3 + S2M3 + S3M3 <=  0
      8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=  0
      9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=  0
     10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
     11)  M1CB + M2CB + M3CB + M4CB + M5CB <=  55
     12)  M1PL + M2PL + M3PL + M4PL + M5PL <=  20
     13)  M1GL + M2GL + M3GL + M4GL + M5GL <=  55
     14)  M1MT + M2MT + M3MT + M4MT + M5MT <=  55
     15)  M1TX + M2TX + M3TX + M4TX + M5TX <=  25
     16)  M1LF1 + M2LF1 <=  210
     17)  M3LF2 + M4LF2 <=  210
     18)  M5LF3 <=  20
     19)  M1CP1 + M2CP1 <=  410
     20)  M3CP2 + M4CP2 <=  410
     21)  M5CP3 <=  40
     22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
     23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
     24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
     25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
     26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
     27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
     28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
     29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
     30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
     31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
     32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
     33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
     34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
     35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
     36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
     37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =   0
     38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =   0
```

39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT = 0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT = 0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT = 0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX = 0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX = 0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX = 0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX = 0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX = 0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 = 0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 = 0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 = 0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 = 0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 = 0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 = 0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 = 0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 = 0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 = 0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 = 0
57) z1=1
58) z3 = 1
59) z5 = 1
END
INTE 5
leave

Scenario 2a

OBJECTIVE FUNCTION VALUE

1) 154270.30

VARIABLE	VALUE	REDUCED COST
Z1	1.000000	36923.000000
Z2	.000000	49615.000000
Z3	1.000000	41298.000000
Z4	.000000	51050.000000
Z5	1.000000	10385.000000
S1M1	428.000000	.000000
S2M1	.000000	14.080000
S3M1	.000000	79.144990
S1M2	.000000	1.020000
S2M2	.000000	15.099990
S3M2	.000000	80.164990
S1M3	.000000	21.070000
S2M3	307.000000	.000000
S3M3	.000000	70.469990
S1M4	.000000	21.070000
S2M4	.000000	.000000
S3M4	.000000	70.469990
S1M5	.000000	32.600000
S2M5	.000000	16.530000
S3M5	32.000000	.000000
M1CB	27.392000	.000000
M2CB	.000000	.000000
M3CB	17.499000	.000000
M4CB	.000000	.000000
M5CB	2.784000	.000000
M1PL	6.848001	.000000
M2PL	.000000	.000000
M3PL	4.912000	.000000
M4PL	.000000	.000000
M5PL	.320000	.000000
M1GL	26.964000	.000000
M2GL	.000000	.000000
M3GL	16.885000	.000000
M4GL	.000000	.000000
M5GL	1.568000	.000000
M1MT	25.680000	.000000
M2MT	.000000	.000000
M3MT	15.964000	.000000
M4MT	.000000	.000000
M5MT	3.488000	.000000
M1TX	10.700000	.000000
M2TX	.000000	.000000
M3TX	8.289001	.000000
M4TX	.000000	.000000
M5TX	.768000	.000000
M1LF1	114.276000	.000000
M2LF1	.000000	.000000
M3LF2	80.741000	.000000
M4LF2	.000000	.000000
M5LF3	8.128000	.000000

M1CP1	216.140000	.000000
M2CP1	.000000	.000000
M3CP2	165.473000	.000000
M4CP2	.000000	.000000
M5CP3	14.944000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-87.735460
3)	.000000	-89.528540
4)	.000000	-19.634590
5)	72.000000	.000000
6)	.000000	.000000
7)	93.000000	.000000
8)	.000000	7.629997
9)	38.000000	.000000
10)	.000000	.000000
11)	7.324999	.000000
12)	7.920000	.000000
13)	9.582999	.000000
14)	9.868000	.000000
15)	5.243000	.000000
16)	95.724010	.000000
17)	129.259000	.000000
18)	11.872000	.000000
19)	193.860000	.000000
20)	244.527000	.000000
21)	25.056000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000
57)	.000000	.000000
58)	.000000	.000000
59)	.000000	.000000

NO. ITERATIONS= 7
BRANCHES= 0 DETERM.= 1.000E 0

```
bat
! Year 1996 Scenario 2b
!
 MIN    36923 Z1 + 49615 Z2 + 41298 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 94.18 S1M3 + 74.18 S2M3 + 79.18 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
      2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   428
      3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   307
      4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   32
      5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=  0
      6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=  0
      7) - 400 Z3 + S1M3 + S2M3 + S3M3 <=  0
      8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=  0
      9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=  0
     10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
     11)  M1CB + M2CB + M3CB + M4CB + M5CB <=  55
     12)  M1PL + M2PL + M3PL + M4PL + M5PL <=  20
     13)  M1GL + M2GL + M3GL + M4GL + M5GL <=  55
     14)  M1MT + M2MT + M3MT + M4MT + M5MT <=  55
     15)  M1TX + M2TX + M3TX + M4TX + M5TX <=  25
     16)  M1LF1 + M2LF1 <=  210
     17)  M3LF2 + M4LF2 <=  210
     18)  M5LF3 <=  20
     19)  M1CP1 + M2CP1 <=  410
     20)  M3CP2 + M4CP2 <=  410
     21)  M5CP3 <=  40
     22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
     23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
     24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
     25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
     26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
     27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
     28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
     29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
     30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
     31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
     32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
     33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
     34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
     35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
     36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
     37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =   0
     38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =   0
```

```
39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT =  0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT =  0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT =  0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX =  0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX =  0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX =  0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX =  0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX =  0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 =  0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 =  0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 =  0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 =  0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 =  0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 =  0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 =  0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 =  0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 =  0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 =  0
END
INTE  5
leave
```

Scenario 2b

OBJECTIVE FUNCTION VALUE

1) 122916.90

VARIABLE	VALUE	REDUCED COST
Z1	.000000	36413.000000
Z2	1.000000	49615.000000
Z3	.000000	35258.000000
Z4	.000000	38970.010000
Z5	.000000	4773.451000
S1M1	.000000	.000003
S2M1	.000000	-.000005
S3M1	.000000	.000000
S1M2	428.000000	.000000
S2M2	307.000000	.000000
S3M2	32.000000	.000000
S1M3	.000000	35.150000
S2M3	.000000	.000000
S3M3	.000000	5.404997
S1M4	.000000	35.150000
S2M4	.000000	.000000
S3M4	.000000	5.404997
S1M5	.000000	111.745000
S2M5	.000000	81.595000
S3M5	.000000	.000000
M1CB	.000000	.000000
M2CB	47.675000	.000000
M3CB	.000000	.000000
M4CB	.000000	.000000
M5CB	.000000	.000000
M1PL	.000000	.000000
M2PL	12.080000	.000000
M3PL	.000000	.000000
M4PL	.000000	.000000
M5PL	.000000	.000000
M1GL	.000000	.000000
M2GL	45.417000	.000000
M3GL	.000000	.000000
M4GL	.000000	.000000
M5GL	.000000	.000000
M1MT	.000000	.000000
M2MT	45.132000	.000000
M3MT	.000000	.000000
M4MT	.000000	.000000
M5MT	.000000	.000000
M1TX	.000000	.000000
M2TX	19.757000	.000000
M3TX	.000000	.000000
M4TX	.000000	.000000
M5TX	.000000	.000000
M1LF1	.000000	.000000
M2LF1	203.145000	.000000
M3LF2	.000000	.000000
M4LF2	.000000	.000000
M5LF3	.000000	.000000

M1CP1	.000000	.000000
M2CP1	396.557000	.000000
M3CP2	.000000	.000000
M4CP2	.000000	.000000
M5CP3	.000000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-88.755460
3)	.000000	-104.628500
4)	.000000	-99.799590
5)	.000000	1.019997
6)	33.000000	.000000
7)	.000000	15.100000
8)	.000000	22.729990
9)	.000000	80.164990
10)	.000000	.000000
11)	7.324999	.000000
12)	7.920000	.000000
13)	9.582999	.000000
14)	9.868000	.000000
15)	5.243000	.000000
16)	6.855000	.000000
17)	210.000000	.000000
18)	20.000000	.000000
19)	13.443010	.000000
20)	410.000000	.000000
21)	40.000000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000

```
NO. ITERATIONS=      31
BRANCHES=    2 DETERM.=  1.000E    0
```

```
bat
! Year 2000 Scenario 3a
!
 MIN    36923 Z1 + 49615 Z2 + 41298 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 94.18 S1M3 + 74.18 S2M3 + 79.18 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
       2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   459
       3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   323
       4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   25
       5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=  0
       6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=  0
       7) - 400 Z3 + S1M3 + S2M3 + S3M3 <=  0
       8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=  0
       9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=  0
      10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
      11)  M1CB + M2CB + M3CB + M4CB + M5CB <=  55
      12)  M1PL + M2PL + M3PL + M4PL + M5PL <=  20
      13)  M1GL + M2GL + M3GL + M4GL + M5GL <=  55
      14)  M1MT + M2MT + M3MT + M4MT + M5MT <=  55
      15)  M1TX + M2TX + M3TX + M4TX + M5TX <=  25
      16)  M1LF1 + M2LF1 <=  210
      17)  M3LF2 + M4LF2 <=  210
      18)  M5LF3 <=  20
      19)  M1CP1 + M2CP1 <=  410
      20)  M3CP2 + M4CP2 <=  410
      21)  M5CP3 <=  40
      22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
      23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
      24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
      25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
      26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
      27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
      28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
      29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
      30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
      31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
      32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
      33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
      34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
      35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
      36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
      37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =   0
      38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =   0
```

```
39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT =  0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT =  0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT =  0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX =  0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX =  0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX =  0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX =  0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX =  0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 =  0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 =  0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 =  0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 =  0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 =  0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 =  0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 =  0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 =  0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 =  0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 =  0
57) z1=1
58) z3 = 1
59) z5 = 1
END
INTE  5
leave
```

Scenario 3a

OBJECTIVE FUNCTION VALUE

1) 158285.20

VARIABLE	VALUE	REDUCED COST
Z1	1.000000	36923.000000
Z2	.000000	49615.000000
Z3	1.000000	41298.000000
Z4	.000000	51050.000000
Z5	1.000000	10385.000000
S1M1	459.000000	.000000
S2M1	.000000	14.080000
S3M1	.000000	79.144990
S1M2	.000000	1.020000
S2M2	.000000	15.099990
S3M2	.000000	80.164990
S1M3	.000000	21.070000
S2M3	323.000000	.000000
S3M3	.000000	70.469990
S1M4	.000000	21.070000
S2M4	.000000	.000000
S3M4	.000000	70.469990
S1M5	.000000	32.600000
S2M5	.000000	16.530000
S3M5	25.000000	.000000
M1CB	29.376000	.000000
M2CB	.000000	.000000
M3CB	18.411000	.000000
M4CB	.000000	.000000
M5CB	2.175000	.000000
M1PL	7.344000	.000000
M2PL	.000000	.000000
M3PL	5.168000	.000000
M4PL	.000000	.000000
M5PL	.250000	.000000
M1GL	28.917000	.000000
M2GL	.000000	.000000
M3GL	17.765000	.000000
M4GL	.000000	.000000
M5GL	1.225000	.000000
M1MT	27.540000	.000000
M2MT	.000000	.000000
M3MT	16.796000	.000000
M4MT	.000000	.000000
M5MT	2.725000	.000000
M1TX	11.475000	.000000
M2TX	.000000	.000000
M3TX	8.721001	.000000
M4TX	.000000	.000000
M5TX	.600000	.000000
M1LF1	122.553000	.000000
M2LF1	.000000	.000000
M3LF2	84.949010	.000000
M4LF2	.000000	.000000
M5LF3	6.350000	.000000

M1CP1	231.795000	.000000
M2CP1	.000000	.000000
M3CP2	174.097000	.000000
M4CP2	.000000	.000000
M5CP3	11.675000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-87.735460
3)	.000000	-89.528540
4)	.000000	-19.634590
5)	41.000000	.000000
6)	.000000	.000000
7)	77.000000	.000000
8)	.000000	7.629997
9)	45.000000	.000000
10)	.000000	.000000
11)	5.037999	.000000
12)	7.237999	.000000
13)	7.092999	.000000
14)	7.939000	.000000
15)	4.204000	.000000
16)	87.447010	.000000
17)	125.051000	.000000
18)	13.650000	.000000
19)	178.205000	.000000
20)	235.903000	.000000
21)	28.325000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000
57)	.000000	.000000
58)	.000000	.000000
59)	.000000	.000000

NO. ITERATIONS= 7
BRANCHES= 0 DETERM.= 1.000E 0

```
bat
! Year 2000 Scenario 3b
!
 MIN    36923 Z1 + 49615 Z2 + 41298 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 94.18 S1M3 + 74.18 S2M3 + 79.18 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
       2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   459
       3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   323
       4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   25
       5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=   0
       6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=   0
       7) - 400 Z3 + S1M3 + S2M3 + S3M3 <=   0
       8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=   0
       9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=   0
      10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
      11)  M1CB + M2CB + M3CB + M4CB + M5CB <=   55
      12)  M1PL + M2PL + M3PL + M4PL + M5PL <=   20
      13)  M1GL + M2GL + M3GL + M4GL + M5GL <=   55
      14)  M1MT + M2MT + M3MT + M4MT + M5MT <=   55
      15)  M1TX + M2TX + M3TX + M4TX + M5TX <=   25
      16)  M1LF1 + M2LF1 <=   210
      17)  M3LF2 + M4LF2 <=   210
      18)  M5LF3 <=   20
      19)  M1CP1 + M2CP1 <=   410
      20)  M3CP2 + M4CP2 <=   410
      21)  M5CP3 <=   40
      22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
      23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
      24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
      25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
      26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
      27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
      28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
      29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
      30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
      31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
      32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
      33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
      34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
      35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
      36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
      37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =   0
      38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =   0
```

39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT = 0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT = 0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT = 0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX = 0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX = 0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX = 0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX = 0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX = 0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 = 0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 = 0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 = 0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 = 0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 = 0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 = 0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 = 0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 = 0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 = 0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 = 0

END
INTE 5
leave

Scenario 3b

OBJECTIVE FUNCTION VALUE

1) 135024.60

VARIABLE	VALUE	REDUCED COST
Z1	.000000	36413.000000
Z2	1.000000	49615.000000
Z3	.000000	35258.000000
Z4	.000000	38970.010000
Z5	1.000000	10385.000000
S1M1	.000000	.000003
S2M1	.000000	.000000
S3M1	.000000	80.164990
S1M2	459.000000	.000000
S2M2	323.000000	.000000
S3M2	.000000	80.164990
S1M3	.000000	35.150000
S2M3	.000000	.000000
S3M3	.000000	85.569990
S1M4	.000000	35.150000
S2M4	.000000	.000000
S3M4	.000000	85.569990
S1M5	.000000	31.580010
S2M5	.000000	1.430000
S3M5	25.000000	.000000
M1CB	.000000	.000000
M2CB	47.787000	.000000
M3CB	.000000	.000000
M4CB	.000000	.000000
M5CB	2.175000	.000000
M1PL	.000000	.000000
M2PL	12.512000	.000000
M3PL	.000000	.000000
M4PL	.000000	.000000
M5PL	.250000	.000000
M1GL	.000000	.000000
M2GL	46.682000	.000000
M3GL	.000000	.000000
M4GL	.000000	.000000
M5GL	1.225000	.000000
M1MT	.000000	.000000
M2MT	44.336000	.000000
M3MT	.000000	.000000
M4MT	.000000	.000000
M5MT	2.725000	.000000
M1TX	.000000	.000000
M2TX	20.196000	.000000
M3TX	.000000	.000000
M4TX	.000000	.000000
M5TX	.600000	.000000
M1LF1	.000000	.000000
M2LF1	207.502000	.000000
M3LF2	.000000	.000000
M4LF2	.000000	.000000
M5LF3	6.350000	.000000

M1CP1	.000000	.000000
M2CP1	405.892000	.000000
M3CP2	.000000	.000000
M4CP2	.000000	.000000
M5CP3	11.675000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-88.755460
3)	.000000	-104.628500
4)	.000000	-19.634590
5)	.000000	1.019997
6)	18.000000	.000000
7)	.000000	15.100000
8)	.000000	22.729990
9)	45.000000	.000000
10)	.000000	.000000
11)	5.037999	.000000
12)	7.237999	.000000
13)	7.092999	.000000
14)	7.939000	.000000
15)	4.204000	.000000
16)	2.498001	.000000
17)	210.000000	.000000
18)	13.650000	.000000
19)	4.108010	.000000
20)	410.000000	.000000
21)	28.325000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000

NO. ITERATIONS= 70
BRANCHES= 6 DETERM.= 1.000E 0

```
bat
! Year 2005 Scenario 4a
!
 MIN   36923 Z1 + 49615 Z2 + 41298 Z3 + 57154 Z4 + 10385 Z5
    + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
    + 85.27 S3M2 + 94.18 S1M3 + 74.18 S2M3 + 79.18 S3M3 + 86.55 S1M4
    + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
    + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
    + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
    - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
    - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
    - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
    + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
    + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
      2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   490
      3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   344
      4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   26
      5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=  0
      6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=  0
      7) - 400 Z3 + S1M3 + S2M3 + S3M3 <=  0
      8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=  0
      9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=  0
     10)  M1PA + M2PA + M3PA + M4PA + M5PA =  0
     11)  M1CB + M2CB + M3CB + M4CB + M5CB <=  55
     12)  M1PL + M2PL + M3PL + M4PL + M5PL <=  20
     13)  M1GL + M2GL + M3GL + M4GL + M5GL <=  55
     14)  M1MT + M2MT + M3MT + M4MT + M5MT <=  55
     15)  M1TX + M2TX + M3TX + M4TX + M5TX <=  25
     16)  M1LF1 + M2LF1 <=  210
     17)  M3LF2 + M4LF2 <=  210
     18)  M5LF3 <=  20
     19)  M1CP1 + M2CP1 <=  410
     20)  M3CP2 + M4CP2 <=  410
     21)  M5CP3 <=  40
     22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =  0
     23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =  0
     24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =  0
     25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =  0
     26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =  0
     27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =  0
     28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =  0
     29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =  0
     30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =  0
     31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =  0
     32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =  0
     33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =  0
     34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =  0
     35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =  0
     36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =  0
     37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =  0
     38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =  0
```

```
   39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT =  0
   40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT =  0
   41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT =  0
   42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX =  0
   43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX =  0
   44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX =  0
   45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX =  0
   46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX =  0
   47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 =  0
   48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 =  0
   49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 =  0
   50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 =  0
   51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 =  0
   52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 =  0
   53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 =  0
   54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 =  0
   55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 =  0
   56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 =  0
   57) z1=1
   58) z3 = 1
   59) z5 = 1
 END
 INTE  5
leave
```

Scenario 4a

OBJECTIVE FUNCTION VALUE

1) 162904.70

VARIABLE	VALUE	REDUCED COST
Z1	1.000000	36923.000000
Z2	.000000	49615.000000
Z3	1.000000	41298.000000
Z4	.000000	51050.000000
Z5	1.000000	10385.000000
S1M1	490.000000	.000000
S2M1	.000000	14.080000
S3M1	.000000	79.144990
S1M2	.000000	1.020000
S2M2	.000000	15.099990
S3M2	.000000	80.164990
S1M3	.000000	21.070000
S2M3	344.000000	.000000
S3M3	.000000	70.469990
S1M4	.000000	21.070000
S2M4	.000000	.000000
S3M4	.000000	70.469990
S1M5	.000000	32.600000
S2M5	.000000	16.530000
S3M5	26.000000	.000000
M1CB	31.360000	.000000
M2CB	.000000	.000000
M3CB	19.608000	.000000
M4CB	.000000	.000000
M5CB	2.262000	.000000
M1PL	7.840000	.000000
M2PL	.000000	.000000
M3PL	5.504000	.000000
M4PL	.000000	.000000
M5PL	.260000	.000000
M1GL	30.870000	.000000
M2GL	.000000	.000000
M3GL	18.920000	.000000
M4GL	.000000	.000000
M5GL	1.274000	.000000
M1MT	29.400000	.000000
M2MT	.000000	.000000
M3MT	17.888000	.000000
M4MT	.000000	.000000
M5MT	2.834000	.000000
M1TX	12.250000	.000000
M2TX	.000000	.000000
M3TX	9.288000	.000000
M4TX	.000000	.000000
M5TX	.624000	.000000
M1LF1	130.830000	.000000
M2LF1	.000000	.000000
M3LF2	90.472000	.000000
M4LF2	.000000	.000000
M5LF3	6.604000	.000000

M1CP1	247.450000	.000000
M2CP1	.000000	.000000
M3CP2	185.416000	.000000
M4CP2	.000000	.000000
M5CP3	12.142000	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-87.735460
3)	.000000	-89.528540
4)	.000000	-19.634590
5)	10.000000	.000000
6)	.000000	.000000
7)	56.000000	.000000
8)	.000000	7.629997
9)	44.000000	.000000
10)	.000000	.000000
11)	1.769999	.000000
12)	6.395999	.000000
13)	3.936000	.000000
14)	4.878000	.000000
15)	2.838000	.000000
16)	79.170010	.000000
17)	119.528000	.000000
18)	13.396000	.000000
19)	162.550000	.000000
20)	224.584000	.000000
21)	27.858000	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	40.000000
48)	.000000	40.000000
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000
57)	.000000	.000000
58)	.000000	.000000
59)	.000000	.000000

NO. ITERATIONS= 7
BRANCHES= 0 DETERM.= 1.000E 0

```
bat
! Year 2005 Scenario 4b
!
 MIN    36923 Z1 + 49615 Z2 + 41298 Z3 + 57154 Z4 + 10385 Z5
     + 69.25 S1M1 + 84.25 S2M1 + 84.25 S3M1 + 70.27 S1M2 + 85.27 S2M2
     + 85.27 S3M2 + 94.18 S1M3 + 74.18 S2M3 + 79.18 S3M3 + 86.55 S1M4
     + 66.55 S2M4 + 71.55 S3M4 + 105.71 S1M5 + 90.71 S2M5 + 8.71 S3M5
     + 21.18 M1CB + 21.18 M2CB + 21.18 M3CB + 21.18 M4CB + 21.18 M5CB
     + 17.27 M1PL + 17.27 M2PL + 17.27 M3PL + 17.27 M4PL + 17.27 M5PL
     - 0.91 M1GL - 0.91 M2GL - 0.91 M3GL - 0.91 M4GL - 0.91 M5GL
     - 62.78 M1MT - 62.78 M2MT - 62.78 M3MT - 62.78 M4MT - 62.78 M5MT
     - 4.09 M1TX - 4.09 M2TX - 4.09 M3TX - 4.09 M4TX - 4.09 M5TX + 40 M1LF1
     + 40 M2LF1 + 35 M3LF2 + 35 M4LF2 + 35 M5LF3 + 20 M1CP1 + 20 M2CP1
     + 15 M3CP2 + 15 M4CP2 + 15 M5CP3
 SUBJECT TO
       2)  S1M1 + S1M2 + S1M3 + S1M4 + S1M5 =   490
       3)  S2M1 + S2M2 + S2M3 + S2M4 + S2M5 =   344
       4)  S3M1 + S3M2 + S3M3 + S3M4 + S3M5 =   26
       5) - 500 Z1 + S1M1 + S2M1 + S3M1 <=  0
       6) - 800 Z2 + S1M2 + S2M2 + S3M2 <=  0
       7) - 400 Z3 + S1M3 + S2M3 + S3M3 <=  0
       8) - 800 Z4 + S1M4 + S2M4 + S3M4 <=  0
       9) - 70 Z5 + S1M5 + S2M5 + S3M5 <=  0
      10)  M1PA + M2PA + M3PA + M4PA + M5PA =   0
      11)  M1CB + M2CB + M3CB + M4CB + M5CB <=  55
      12)  M1PL + M2PL + M3PL + M4PL + M5PL <=  20
      13)  M1GL + M2GL + M3GL + M4GL + M5GL <=  55
      14)  M1MT + M2MT + M3MT + M4MT + M5MT <=  55
      15)  M1TX + M2TX + M3TX + M4TX + M5TX <=  25
      16)  M1LF1 + M2LF1 <=  210
      17)  M3LF2 + M4LF2 <=  210
      18)  M5LF3 <=  20
      19)  M1CP1 + M2CP1 <=  410
      20)  M3CP2 + M4CP2 <=  410
      21)  M5CP3 <=  40
      22)  0.064 S1M1 + 0.057 S2M1 + 0.087 S3M1 - M1CB =   0
      23)  0.064 S1M2 + 0.057 S2M2 + 0.087 S3M2 - M2CB =   0
      24)  0.064 S1M3 + 0.057 S2M3 + 0.087 S3M3 - M3CB =   0
      25)  0.064 S1M4 + 0.057 S2M4 + 0.087 S3M4 - M4CB =   0
      26)  0.064 S1M5 + 0.057 S2M5 + 0.087 S3M5 - M5CB =   0
      27)  0.016 S1M1 + 0.016 S2M1 + 0.01 S3M1 - M1PL =   0
      28)  0.016 S1M2 + 0.016 S2M2 + 0.01 S3M2 - M2PL =   0
      29)  0.016 S1M3 + 0.016 S2M3 + 0.01 S3M3 - M3PL =   0
      30)  0.016 S1M4 + 0.016 S2M4 + 0.01 S3M4 - M4PL =   0
      31)  0.016 S1M5 + 0.016 S2M5 + 0.01 S3M5 - M5PL =   0
      32)  0.063 S1M1 + 0.055 S2M1 + 0.049 S3M1 - M1GL =   0
      33)  0.063 S1M2 + 0.055 S2M2 + 0.049 S3M2 - M2GL =   0
      34)  0.063 S1M3 + 0.055 S2M3 + 0.049 S3M3 - M3GL =   0
      35)  0.063 S1M4 + 0.055 S2M4 + 0.049 S3M4 - M4GL =   0
      36)  0.063 S1M5 + 0.055 S2M5 + 0.049 S3M5 - M5GL =   0
      37)  0.06 S1M1 + 0.052 S2M1 + 0.109 S3M1 - M1MT =   0
      38)  0.06 S1M2 + 0.052 S2M2 + 0.109 S3M2 - M2MT =   0
```

```
39) 0.06 S1M3 + 0.052 S2M3 + 0.109 S3M3 - M3MT =  0
40) 0.06 S1M4 + 0.052 S2M4 + 0.109 S3M4 - M4MT =  0
41) 0.06 S1M5 + 0.052 S2M5 + 0.109 S3M5 - M5MT =  0
42) 0.025 S1M1 + 0.027 S2M1 + 0.024 S3M1 - M1TX =  0
43) 0.025 S1M2 + 0.027 S2M2 + 0.024 S3M2 - M2TX =  0
44) 0.025 S1M3 + 0.027 S2M3 + 0.024 S3M3 - M3TX =  0
45) 0.025 S1M4 + 0.027 S2M4 + 0.024 S3M4 - M4TX =  0
46) 0.025 S1M5 + 0.027 S2M5 + 0.024 S3M5 - M5TX =  0
47) 0.267 S1M1 + 0.263 S2M1 + 0.254 S3M1 - M1LF1 =  0
48) 0.267 S1M2 + 0.263 S2M2 + 0.254 S3M2 - M2LF1 =  0
49) 0.267 S1M3 + 0.263 S2M3 + 0.254 S3M3 - M3LF2 =  0
50) 0.267 S1M4 + 0.263 S2M4 + 0.254 S3M4 - M4LF2 =  0
51) 0.267 S1M5 + 0.263 S2M5 + 0.254 S3M5 - M5LF3 =  0
52) 0.505 S1M1 + 0.539 S2M1 + 0.467 S3M1 - M1CP1 =  0
53) 0.505 S1M2 + 0.539 S2M2 + 0.467 S3M2 - M2CP1 =  0
54) 0.505 S1M3 + 0.539 S2M3 + 0.467 S3M3 - M3CP2 =  0
55) 0.505 S1M4 + 0.539 S2M4 + 0.467 S3M4 - M4CP2 =  0
56) 0.505 S1M5 + 0.539 S2M5 + 0.467 S3M5 - M5CP3 =  0
END
INTE  5
leave
```

Scenario 4b

OBJECTIVE FUNCTION VALUE

1) 140054.30

VARIABLE	VALUE	REDUCED COST
Z1	.000000	36413.000000
Z2	1.000000	49615.000000
Z3	.000000	34686.000000
Z4	.000000	37826.000000
Z5	1.000000	10385.000000
S1M1	.000000	.000003
S2M1	.000000	.000000
S3M1	.000000	81.546070
S1M2	490.000000	.000000
S2M2	301.026600	.000000
S3M2	.000000	81.546070
S1M3	.000000	35.128250
S2M3	.000000	.000000
S3M3	.000000	86.999990
S1M4	.000000	35.128250
S2M4	.000000	.000000
S3M4	.000000	86.999990
S1M5	.000000	30.128250
S2M5	42.973380	.000000
S3M5	26.000000	.000000
M1CB	.000000	.000000
M2CB	48.518520	.000000
M3CB	.000000	.000000
M4CB	.000000	.000000
M5CB	4.711483	.000000
M1PL	.000000	.000000
M2PL	12.656430	.000000
M3PL	.000000	.000000
M4PL	.000000	.000000
M5PL	.947574	.000000
M1GL	.000000	.000000
M2GL	47.426460	.000000
M3GL	.000000	.000000
M4GL	.000000	.000000
M5GL	3.637536	.000000
M1MT	.000000	.000000
M2MT	45.053380	.000000
M3MT	.000000	.000000
M4MT	.000000	.000000
M5MT	5.068615	.000000
M1TX	.000000	.000000
M2TX	20.377720	.000000
M3TX	.000000	.000000
M4TX	.000000	.000000
M5TX	1.784281	.000000
M1LF1	.000000	.000000
M2LF1	210.000000	.000000
M3LF2	.000000	.000000
M4LF2	.000000	.000000
M5LF3	17.906000	.000000

M1CP1	.000000	.000000
M2CP1	409.703300	.000000
M3CP2	.000000	.000000
M4CP2	.000000	.000000
M5CP3	35.304650	.000000
M1PA	.000000	.000000
M2PA	.000000	.000000
M3PA	.000000	.000000
M4PA	.000000	.000000
M5PA	.000000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-90.207210
3)	.000000	-106.058500
4)	.000000	-19.634590
5)	.000000	1.019997
6)	8.973378	.000000
7)	.000000	16.530000
8)	.000000	24.160000
9)	1.026622	.000000
10)	.000000	.000000
11)	1.769999	.000000
12)	6.395999	.000000
13)	3.936000	.000000
14)	4.878000	.000000
15)	2.838000	.000000
16)	.000000	5.437272
17)	210.000000	.000000
18)	2.094001	.000000
19)	.296661	.000000
20)	410.000000	.000000
21)	4.695350	.000000
22)	.000000	21.180000
23)	.000000	21.180000
24)	.000000	21.180000
25)	.000000	21.180000
26)	.000000	21.180000
27)	.000000	17.270000
28)	.000000	17.270000
29)	.000000	17.270000
30)	.000000	17.270000
31)	.000000	17.270000
32)	.000000	-.910000
33)	.000000	-.910000
34)	.000000	-.910000
35)	.000000	-.910000
36)	.000000	-.910000
37)	.000000	-62.780000
38)	.000000	-62.780000
39)	.000000	-62.780000
40)	.000000	-62.780000
41)	.000000	-62.780000
42)	.000000	-4.090000
43)	.000000	-4.090000
44)	.000000	-4.090000
45)	.000000	-4.090000

46)	.000000	-4.090000
47)	.000000	45.437270
48)	.000000	45.437270
49)	.000000	35.000000
50)	.000000	35.000000
51)	.000000	35.000000
52)	.000000	20.000000
53)	.000000	20.000000
54)	.000000	15.000000
55)	.000000	15.000000
56)	.000000	15.000000

NO. ITERATIONS= 64
BRANCHES= 6 DETERM.= 1.000E 0